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Eco Logic International Gas-Phase Chemical Reduction Process-The Thermal Desorption Unit

Applications Analysis Report

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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Notice

The information in this document has been funded by the U.S. Environmental Protection Agency (EPA) under the auspices of the Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-C9-0033 to Foster Wheeler Enviresponse, Inc. (FWEI). It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

The SITE Program was authorized in the 1986 Superfund Amendments and Reauthorization Act (SARA). The program is administered by EPA's Office of Research and Development (ORD). The purpose of the program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This is accomplished through technology demonstrations designed to provide performance and cost data on selected technologies.

The SITE Program funded a field demonstration to evaluate the EC0 LOGIC Gas-Phase Chemical Reduction Process, developed by ELI Eco Logic International, Inc., Ontario, Canada. The EC0 LOGIC Demonstration took place at the Middleground Landfill in Bay City, Michigan, using landfill waste; it assessed the technology's ability to treat hazardous wastes, based on performance and cost. Three reports contain the results of the Demonstration: a Technology Evaluation Report (TER), which describes the field activities and laboratory results; this Applications Analysis Report (AAR), which interprets the data and discusses the applicability of the technology to a soil feedstock; and a second, independent AAR, which interprets the data and discusses the applicability of the reactor system to liquid feedstocks.

A limited number of copies of this report will be available at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, OH 45268 (513-569-7562). Requests should include the EPA document number found on the report's front cover. When this supply is exhausted, additional copies can be purchased from the National Technical Information Service, Ravensworth Bldg., Springfield, VA 22161, 703-487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. To inquire about the availability of other reports, call the EPA Clearinghouse Hotline at l-800-424-9346 or 202-382-3000 in Washington, DC.

E. Timothy Oppelt, Director
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Abstract

This report evaluates the capability of the EC0 LOGIC Gas-Phase Chemical Reduction Process to detoxify organics in a solid matrix. The report presents data from the recent EPA SITE Demonstration, which tested the EC0 LOGIC Thermal Desorption Unit (TDU), and evaluates the costs of operating the unit.

The EC0 LOGIC Process thermally separates organics, then chemically reduces them in a hydrogen atmosphere, converting them to a reformed gas that consists of light hydrocarbons and water. EC0 LOGIC designed the TDU to remove organic and metallic contaminants from soil, sending the desorbed organics to the reactor system for further treatment. The TDU produces two principal residual streams: treated soil and quench water.

The SITE Program evaluated the EC0 LOGIC Process at the Middleground Landfill in Bay City, Michigan. There, the TDU/reactor system processed 1.1 tons of soils, contaminated principally with polychlorinated biphenyls(PCBs). The test did not demonstrate successful treatment of contaminated soils. Rather, it provided proof-of-concept data to evaluate the system's strengths and weaknesses; it focused attention on the areas that require additional engineering evaluation or change.

Contents

Contents (Continued)

Figures

Tables

Abbreviations

AAR	Applications Analysis Report
AAS	atomic absorption spectroscopy
ARARs	applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
CAA	Clean Air Act
CB	chlorobenzene
CEM	continuous emission monitoring
CEMS	continuous emissions monitoring system
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CIMS	Chemical Ionization Mass Spectrometer
C O	carbon monoxide
CO_2	carbon dioxide
CP	chlorophenols analysis
Cl	chloride
Cl_2	chlorine
CVAAS	cold vapor atomic absorption spectroscopy
CWA	Clean Water Act
DE	destruction efficiency
DOT	U.S. Department of Transportation
DRE	destruction and removal efficiency
dscf	dry standard cubic foot
dscm	dry standard cubic meter
EER	Energy and Environmental Research Corp.
EC0 LOGIC	ELI Eco Logic International, Inc.
EPA	U.S. Environmental Protection Agency
FID	flame ionization detection
ft	feet
FPD	flame photometric detector
FWEI	Foster Wheeler Enviresponse, Inc.
g	gram

Abbreviations (Continued)

GC	gas chromatography
GF	graphite furnace
gr	grains
gpm	gallons per minute
H_2	hydrogen
HCB	hexachlorobenzene
HCI	hydrogen chloride
hr	hour
HR	high resolution
ICAP	inductively coupled argon plasma spectroscopy
in.	inch
kg	kilogram
kW	kilowatt
L	liter
lb	pound
MASA	Method of Air Sampling and Analysis
MDNR	Michigan Department of Natural Resources
m	meter
mg	milligram
min	minute
mo	month
MS	mass spectroscopy
NAAQS	National Ambient Air Quality Standards
NDIR	nondispersive infrared
NDUV	nondispersive ultraviolet
ng	nanogram
NO_x	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
O_2	oxygen
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
OSHA	Occupational Safety and Health Act
PAHS	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCDD	polychlorinated dibenzo-p-dioxin
PCDF	polychlorinated dibenzofuran
PCE	perchloroethylene
PH	a measure of acidity/alkalinity
PICs	products of incomplete combustion

Abbreviations (Continued)

PIR	product of incomplete reduction
POHC	principal organic hazardous constituent
POTW	publicly owned treatment works
ppb	parts per billion
PPE	personal protective equipment
ppm	parts per million
ppmv	parts per million by volume
psig	pounds per square inch gauge
QA	quality assurance
QI	quality indicator
RCRA	Resource Conservation and Recovery Act
RREL	Risk Reduction Engineering Laboratory
SARA	Superfund Amendments and Reauthorization Act
scf	standard cubic feet
scfm	standard cubic feet per minute
sec	second
SITE	Super-fund Innovative Technology Evaluation Program
SO_2	sulfur dioxide
SVOCs	semivolatile organic compounds
TCLP	Toxicity Characteristic Leaching Procedure
TDU	thermal desorption unit
TER	Technology Evaluation Report
THC	total hydrocarbon
TSCA	Toxic Substances Control Act
TSD	treatment, storage, and disposal
VOCs	volatile organic compounds
VOST	volatile organic sampling train
µg	microgram

SI Conversion Factors

Multiply	English (US) Units	by	Factor	to get	Metric (SI) Units
Area:	1 ft^2		0.0929		m^2
	1 $in.^2$		6.452		cm^2
Flow rate:	1 gal/min		6.31 x 10^{-5}		m^3/s
	1 gal/min		0.063 1		L / S
	1 MGD		43.81		L / S
Length:	1 ft		0.3048		m
	1 in.		2.54		cm
Mass:	1 lb		453.59		g
	1 lb		0.45359		kg
Volume:	1 ft^3		28.316		L
	1 ft^3		0.0283 17		m^3
	1 gal		3.785		L
	1 gal		0.003785		m^3
Temperature:	°F - 32		0.55556		°C
Concentration:	1 gr/ft^3		2.2884		g/m^3
	1 gr/gal		0.0171		g/L
	1 lb/ft^3		16.03		g/L
Pressure:	1 $lb/in.^2$		0.0703 1		kg/cm^2
	1 lb/in.2		6894.8		Newton/m^2
Heating value:	Btu/lb		2326		Joules/kg
	Btu/scf		37260		Joules/scm

Acknowledgments

Under EPA Contract 68-C9-0033, FWEI prepared this report for EPA's SITE Program with the supervision and guidance of Gordon M. Evans, EPA SITE Program Manager in the Risk Reduction Engineering Laboratory (RREL), Cincinnati, Ohio. The FWEI Project Manager was Gerard W. Sudell; James P. Stumbar, Ph.D., provided the technical review; Marilyn K. Avery edited the document.

Energy and Environmental Research Corporation (EER) provided sampling and analytical support to EPA. Contracted to perform data analysis, data reduction, and analytical review, EER provided the scientific data that form the basis for this report.

Kelvin Campbell and Craig McEwen of ELI Eco Logic International provided continued assistance throughout the project, as did Edward Golson of the City of Bay City. Sue Kaelber-Mattock supported the project for the Michigan Department of Natural Resources.

Section 1
Executive Summary

Introduction

This report summarizes the findings of the SITE Demonstration of the Gas-Phase Chemical Reduction Process and TDU developed by ELI Eco Logic, International, Inc. (EC0 LOGIC) of Ontario, Canada.

Under the auspices of the SITE Program, and in cooperation with the City of Bay City, Michigan; Environment Canada; and Ontario Ministry of the Environment and Energy; EPA conducted the demonstration of the EC0 LOGIC Process at Bay City's Middleground Landfill. The landfill accepted municipal and industrial wastes for approximately 40 years. A 1991 remedial investigation indicated elevated levels in groundwater of trichloroethene, PCBs, 1 ,2-dichloroethene methyl-. ene chloride, toluene, and ethylbenzene. The groundwafer contained lesser concentrations of benzidine, benzene, vinyl chloride, chlorobenzenes, polycyclic aromatic hydrocarbons (PAHs), lindane, dieldrin, chlordane, and DDT metabolites.

The patented EC0 LOGIC Gas-Phase Chemical Reduction Process treats organic hazardous waste in soil and liquid media. During processing, the soil waste feed enters a TDU designed to desorb and evaporate organics from solids. Treated solids are cooled and stored for proper disposal. The evaporated organics pass to the reactor where they are treated with PCB-contaminated liquids and water in the gas-phase chemical reduction reactor to produce reformed gas.

The reaction products include hydrogen chloride from the reduction of chlorinated organics, such as PCBs, and lighter hydrocarbons, such as methane and ethylene, from the reduction of straight-chain and aromatic hydrocarbons. The absence of free oxygen in the reactor inhibits dioxin formation. Water acts as a hydrogen donor to enhance the reaction.

A scrubber treats the reformed gas to remove hydrogen chloride and particulats Of this gas, a portion recycles back into the reactor; the rest is either stored or feeds a propane-fired boiler prior to release to the atmosphere. The recycle stream may be used as a fuel in other system support equipment, such as the boiler that generates steam. The final combustion step in the boiler met Resource Conservation and Recovery Act (RCRA) requirements, making the reformed gas environmentally acceptable for combustion.

The SITE Demonstration

The two-part demonstration took place in October and December 1992 , using PCB-contaminated oil, water, and soil extracted directly from the landfill. EC0 LOGIC first performed a series of shakedown tests to establish optimum system performance. Two liquid tests investigated reactor performance (Conditions 1 and 3); a soil test (Condition 2) studied the complementary TDU. The TDU test consisted of two runs, processing a total of 1.1 tons of soil contaminated with 627 ppm of PCB. This report provides only the results for the soil test; a second, independent AAR has published the results of the two liquid tests.

EPA collected extensive samples around the major system components and stored or logged important data on operating and utility usage. Laboratory analyses provided information on the principal process streams: desorbed soil, reactor grit, scrubber residuals, reformed gas, and boiler stack emissions. EPA evaluated these data against established program objectives to determine the capability of the process to treat the designated waste.

Conclusions

Based on the program objectives, the demonstration confirmed the feasibility of the gas-phase chemical reduction process for treating PCBs and other chlorinated organic compounds, producing a fuel gas from PCB-contaminated soil, and providing environmentally acceptable air emissions.

The TDU did not perform to design specifications. EPA categorized the TDU test data as a system proof-of-concept rather than as a comprehensive evaluation of a fully developed unit. The test data indicated that the TDU, as presently configured, achieved desorption efficiencies at the expense of throughput. In addition, EC0 LOGIC experienced material handling problems with the TDU feed. The combination of material handling problems and inadequate organics desorption showed a need for further development. The test data have identified system strengths and targeted areas that require improvement.

Nevertheless, the demonstration did show that EC0 LOGIC's TDU can desorb PCB contaminants. Subsequent treatment of the desorbed gas in the reactor produced stack emissions that generally met stringent regulatory levels. The reformed gas composition resembled coal-gas fuel. The scrubber liquor required either disposal as a RCRA waste or recycling through the system for additional treatment. Table 1 correlates the program conclusions with the program objectives.

Waste Applicability

The SITE Program concluded that the EC0 LOGIC Process, from the reactor to the stack (independent of the TDU), efficiently treated liquid wastes containing oily PCBs, other organics, and water containing PCBs, other organics, and metals. Stack emissions met stringent regulatory levels. An independent AAR presents the results of the reactor tests.

The reactor did not directly process soil. Instead, EC0 LOGIC provided a complementary front-end TDU to treat soils. The principal TDU residual streams were the quench water and the treated soil. PCB concentrations ranged from 8.26 to 29.2 ppm in the treated soil, resulting from inadequate desorption of semivolatile organic compounds (SVOCs). Based on this result and others discussed in Section 3, the TDU requires further development to successfully process contaminated soils.

Costs

The twelve categories established for the SITE Program formed the basis for the cost analysis. Costs relate to the TDU, as operated at the Middleground Landfill: Based on the economic analysis, the estimated cost (1994 U.S. dollars) for treating solid wastes similar to those at the Bay City site range from $630/ ton (at a 60% utilization factor) t o $500/ton (80% utilization factor). Important elements affecting costs are fuel (67%). equipment (11%). and labor (9%). The rest of the cost components comprised 13%.

Table 1. Summary Results **of** TDU Testing

Objective	Results: Met	Not met	Range achieved	Comments
Demonstrate DRE for PCBs: 99.9999%	X		99.9999%	Requirements met.
Demonstrate DE for HCB: 99.99%		X	72.13 to 99.99%	Inefficient desorption from soil in Run 1.
Ensure no formation of PCDD/PCDF	**X**		PCDD DE: 42.5% to 99.45% PCDF DE: 54.6% to 96.12%	No net PCDD/PCDF formation..
Characterize PIC emissions	X			Emissions characterized.
Characterize HCI emissions	X		0.66 mg/dscm; 150 mg/hr; 99.96% removal	HCI emissions acceptable.
Document MDNR air permit compliance	X			Air permit compliance documented.
Characterize criteria air pollutants	X			Easily met permit conditions.
Validate key cost assumptions	X			Cost elements identified.
Characterize effluents and residuals	X			Organics destroyed; metals partitioned to quench water and scrubber water; after further treatment, scrubber liquor may be suitable for POTW.
Determine suitability of reformed gases for reuse/resale	**X**			Closely matched composition of other commercial fuel gases.
Demonstrate system reliability	**X**		Throughput reliability: 4 to 21.2% of design. System availability: 24%	Process reliability requires improvement.
Develop mass balances	**X**			Generally good closures, except for certain metals.
Characterize scale-up parameters	**X**			Characterized
Validate CIMS		X		May reflect data trends useful for process control.
Document system operating conditions	X			Data available for commercial scaleup.

Section 2
Introduction

The SITE Program

In 1986 EPA's Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD) established the SITE Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its eighth year, SITE is helping to commercialize the treatment technologies necessary to meet new federal and state cleanup standards aimed at permanent remedies, rather than short-term corrections. The SITEProgram includes four major elements: the Demonstration Program, the Emerging Technologies Program, the Measurement and Monitoring Technologies Program, and the Technology Transfer Program.

The major focus has been on the Demonstration Program, designed to provide engineering and cost data on selected technologies. EPA and the technology developers that participate in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems, usually at Superfund sites selected by EPA. EPA is responsible for sampling, analyzing, and evaluating test results. The outcome is an assessment of the technology's performance, reliability, and cost. This information, used in conjunction with other data, enables EPA and state decision makers to select the most appropriate technologies for Superfund cleanups.

Innovative technology developers apply to participate in the Demonstration Program by responding to EPA's annual solicitation. EPA will consider a proposal at any time from a developer who has scheduled a treatment project on Superfund waste. To qualify for the program, a new technology must have a pilot- or full-scale unit and offer some advantage over existing technologies. Mobile technologies are particularly interesting.

Once a proposal has been accepted, EPA and the developer work with the EPA regional offices and state agencies to identify a site containing wastes suitable for testing the technology. EPA prepares a detailed sampling and analysis plan designed to thoroughly evaluate the technology by providing analysts with reliable data. A demonstration may last anywhere from a few days to several months, depending on the process and the quantity of waste needed to assess the technology. Ultimately, the Demonstration Program rates the technology's overall applicability to Superfund problems.

The second major element of the SITE Program is the Emerging Technologies Program, which fosters the further investigation and development of treatment technologies that are still at laboratory scale. Successful validation of these technologies could lead to the development of systems viable for field demonstration. A third component of the SITE Program, the Measurement and Monitoring Technologies Program, provides assistance in the development and demonstration of innovative technologies that will better characterize Superfund sites. The Technology Transfer component ensures effective distribution of the results of the demonstration projects.

SITE Program Reports

Two documents incorporate the results of each SITE Demonstration: the TER and the AAR. The TER contains a comprehensive description of the demonstration and its results. This report assists engineers who are performing a detailed evaluation of the technology for a specific site and waste. The technical evaluations provide a detailed understanding of the technology performance during the demonstration and assess the advantages, risks, and costs for a given application.

The AAR estimates Superfund applications and technology costs, based on available data. It compiles design and test data, summarizes them, explores other laboratory and field applications, and discusses the advantages, disadvantages, and limitations of the technology. The AAR attempts to synthesize available information and draw reasonable conclusions for the technology's use. The report discusses factors such as site and waste characteristics that have a major effect on costs and performance. Pilot- and full-scale operations data provide the bases for estimating technology costs for different applications.

The amount of available data needed to evaluate an innovative technology varies widely. Data may be limited to laboratory tests on synthetic waste or may extend to performance data on actual wastes treated in the field at the pilot or full scale. In addition, conclusions regarding Superfund applications drawn from a single field demonstration have limitations. A successful field demonstration does not necessarily ensure that a technology will become widely applicable or attain full development at the commercial scale. The AAR can assist remedial managers in planning Superfund cleanups; it represents an important tool in the development and commercialization of the technology.

Key Contacts

The sources listed below can provide additional information concerning the SITE Demonstration, the site, or the EC0 LOGIC Gas-Phase Chemical Reduction Process.

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Section 3
Technology Applications Analysis

This AAR assesses the capability of the EC0 LOGIC TDU to treat soils contaminated with PCBs and other hazardous substances. EPA has based the assessment on the results of the SITE Demonstration and on data supplied by the technology developer. The report contains a summary of relevant material from the more detailed TER. Since the results of the demonstration, provided in the TER, are of known quality, the report bases its conclusions on them.

Appendix A describes the demonstration sampling and analytical locations/methods; Appendix B, EC0 LOGIC's claims for the technology.

Process Description

The patented EC0 LOGIC Gas-Phase Chemical Reduction Process (Reactor System) treats organic hazardous waste in a hydrogen-rich atmosphere at approximately 900°C (1,650°F) and ambient pressure, producing a reformed gas. Water acts as a hydrogen donor to enhance the reaction. The reaction products include hydrogen chloride, from the reduction of chlorinated organics, such as PCBs, and lighter hydrocarbons, such as methane and ethylene from the reduction of straight-chain and aromatic hydrocarbons. A scrubber treats the reformed gas to remove hydrogen chloride and particulates. Of this gas, a portion recycles back into the reactor; the rest is either compressed for storage or feeds a propane-fired boiler prior to release to the atmosphere. The absence of free oxygen in the reactor inhibits dioxin formation.

Figure 1 shows some of the reactions that lead to the major intermediate and final products. Through hydrogenation, the first five reactions remove chlorine from PCBs and reduce the higher molecular weight hydrocarbons to simpler, more saturated compounds. The final reaction regenerates hydrogen.

Figure 2 illustrates the process in a schematic diagram of the field demonstration unit. The demonstration-scale reactor (Figure 3) is mounted on a drop-deck trailer. The trailer carries a scrubber system, a recirculation gas system, and an electrical control center. A second trailer holds a propane boiler, a waste preheating vessel, and a waste storage tank.

EC0 LOGIC designed the TDU/reactor process to treat 4 tons/day of waste oil, 10 tons/day of wastewater, and 25 tons/day of soil, depending on the nature of the contaminants, their degree of chlorination, and their water content.

The TDU processes soil by desorbing organics at 500-600°C (930-1,1 10°F) into a hydrogen-rich carrier gas and by dissolving volatile metals in a molten metal bath. Some of each volatile metal will pass to the reactor with the carrier gas, an additional portion will be dissolved into the bath, and the remainder will stay in the treated soil. Nonvolatile metals remain in the treated soil; quench water cools the treated soil prior to disposal. The hydrogen-rich carrier gas conveys the desorbed organics to the reactor (Figure 3). where they are treated in a gas-phase chemical reduction reaction to produce reformed gas.

Hydrogen and molten tin are used because the two elements do not react, unlike other combinations such as tin and oxygen. Tin offers favorable properties: high thermal conductivity, high density, low vapor pressure, and high surface tension. Tin's high thermal conductivity makes it a good heat transfer fluid, efficiently raising the soil temperature. Its high density causes the soil to float on the bath's surface, preventing its mixing with the tin. Low vapor pressure prevents evaporation of the tin. Because it has a high surface tension and is nonwetting, molten tin does not soak into the pores between soil particles. Hence, the treated soil is easily separated. In addition, molten tin is a good solvent for heavy metals such as lead, arsenic, and cadmium. If these metals are present in the elemental state, they dissolve into the bath. If they are present as oxides or as other compounds, the hot hydrogen atmosphere can convert them to an elemental state.

During the tests, a hopper with a screw feeder dropped waste soil onto the tin bath. The screw feeder provided a gas seal between the outside air and the hydrogen atmosphere inside the TDU. The auger's variable speed drive controlled the feed rate. Once inside the TDU, the soil floated on top of the molten tin and heated to 600°C (1,110°F) Organic materials vaporized from the soil and flowed to the reactor with the hydrogen carrier gas. A paddlewheel removed treated soil from the end of the tin bath and fed it into a quench tank. A drag conveyor removed the soil from the quench tank.

For the demonstration, a heat exchanger evaporated contaminated aqueous feedstock to form steam and a concentrated heated liquor. Atomizing nozzles sprayed the heated liquor, with associated particulates, into the reactor. A separate pump sent PCB-rich oils directly to the reactor through other atomizing nozzles. Compressed hydrogen-rich recirculation gas passed through a gas-fired heat exchanger and entered the top

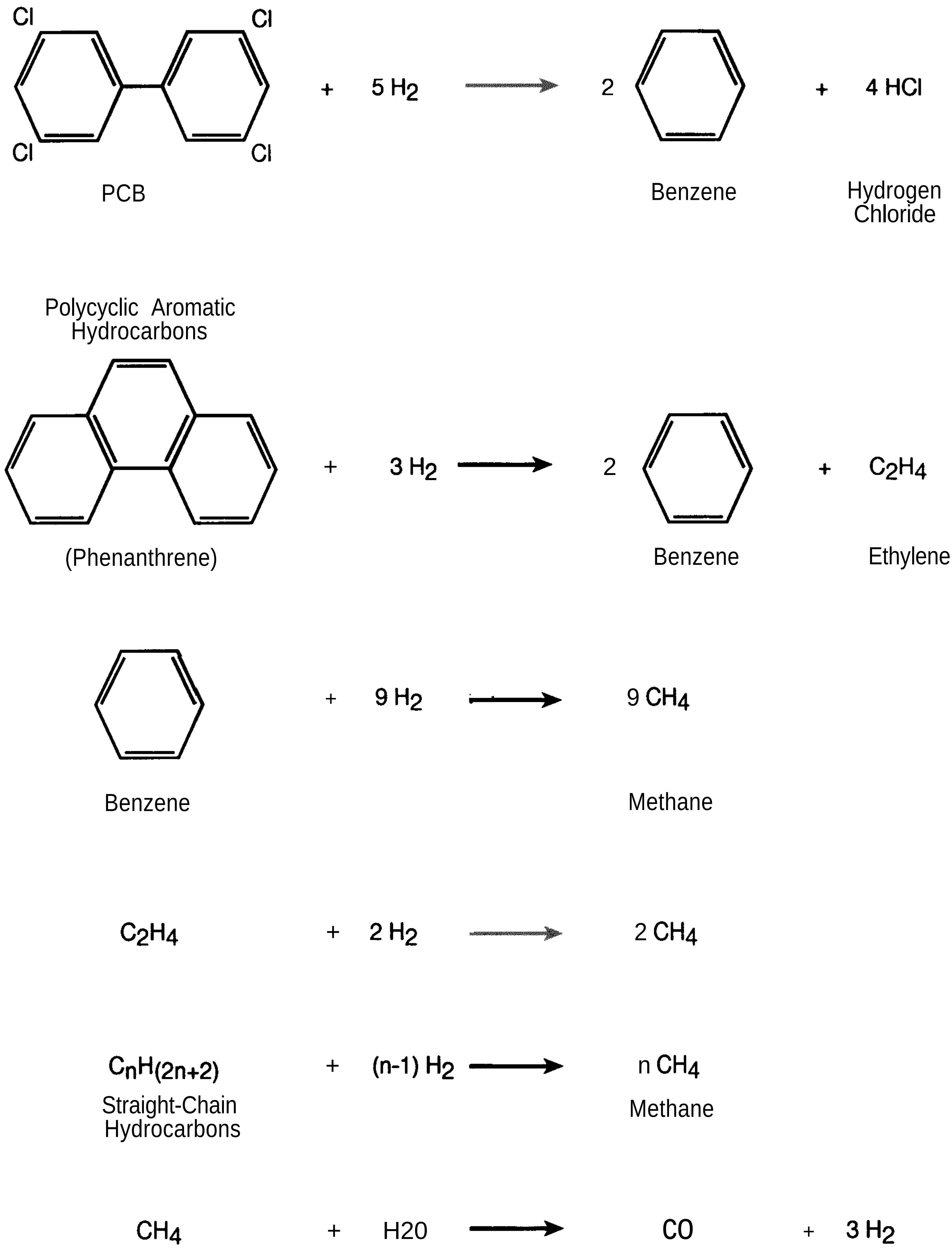


Figure 1. Gas-phase chemical reduction reactions.

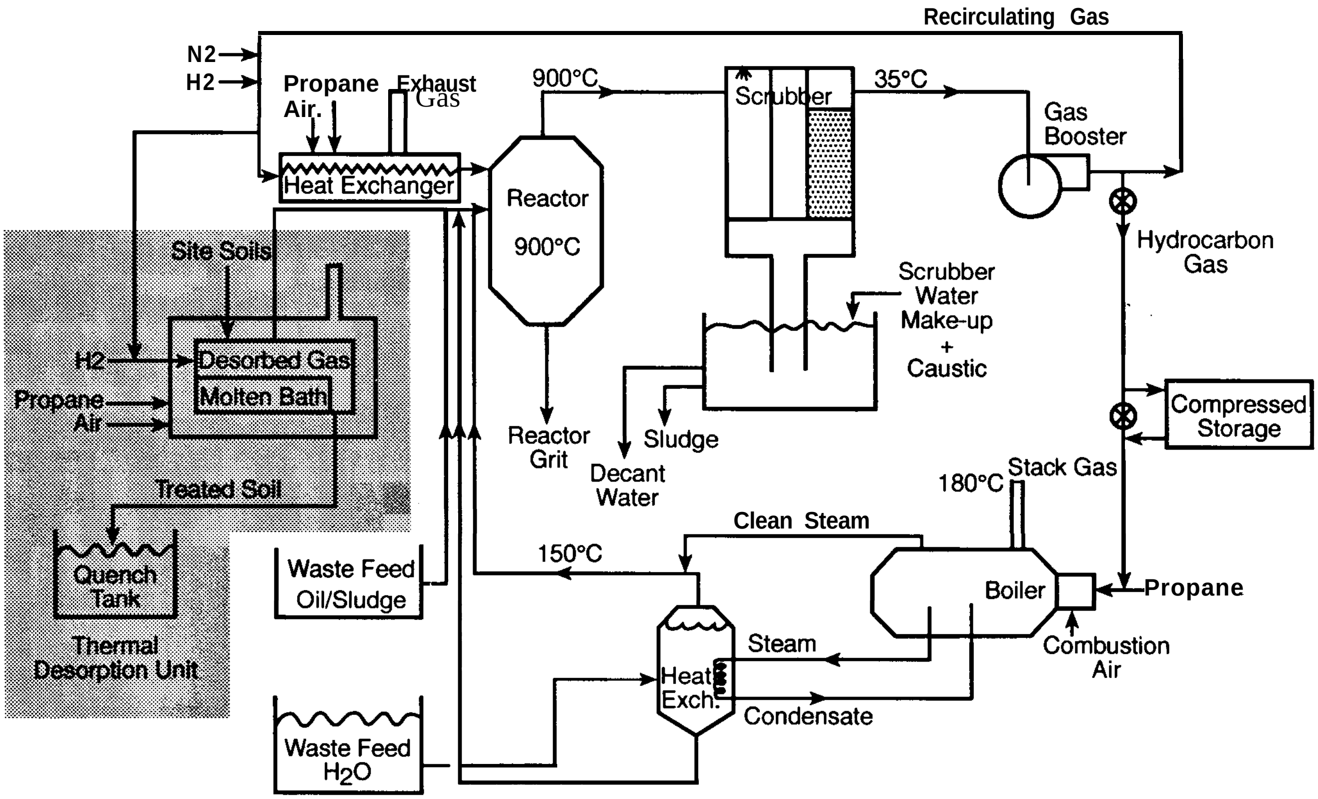


Figure 2. Reactor and TDU system schematic diagram.

of the reactor tangentially. The tangential entry swirled the fluids to provide effective mixing. As indicated in Figure 3, the swirling mixture traveled downward in the annulus formed by the reactor wall and the central ceramic-coated steel tube, past electrically heated bars. These bars heated the mixture to 900°C (1,650'F) At the bottom of the reactor the mixture entered the tube, reversed direction, and flowed upward to the outlet of the reactor. The reduction reactions occurred as the gases traveled from the reactor inlets to the scrubber inlet.

After quenching, the gases flowed through a scrubber where contact with water removed hydrogen chloride and fine particulates. A large water-sealed vent, acting as an emergency pressure relief duct, passed scrubber water to a tank below. A pump recirculated the scrubber water in a loop through an evaporative cooler to reduce its temperature to 35°C (95°F). Caustic and make-up water, added to the scrubber liquor, maintained hydrogen chloride removal efficiency. The scrubber produced two effluent streams: sludge and decant water.

The reformed gas exiting the scrubber contained excess hydrogen, lighter hydrocarbon reduction products such as methane and ethylene, and a small amount of water vapor. A portion of this hydrogen-rich gas was reheated to 500°C (930°F) and recirculated back into the reactor; the rest of the gas served as supplementary fuel for a propane-fired boiler. The boiler produced steam used in the heat exchanger and burned the reformed gas, which was the only air emission from the process.

When treating wastes containing highly concentrated organits, the process generates excess reformed gas. The system can compress the reformed gas and store it for later use as fuel in other parts of the process.

Test Conditions

In preparation for the SITE Demonstration ECO LOGIC first adjusted the system to obtain peak performance, then performed a tracer material pretest to adjust sampling equipment and trains. Two test runs (Conditions 1 and 3) followed over the next 17 days; they introduced PCB-contaminated liquids directly to the reactor. During two additional test runs (Condition 2) over an additional nine-day period the TDU processed PCB-contaminated soil, sending desorbed gases to the reactor for further treatment. The two runs treated 1.1 tons of soil contaminated with 627 ppm of PCB and 14,693 ppm of hexachlorobenzene (HCB) (tracer).

The ECO LOGIC SITE Demonstration objectives were as follows:

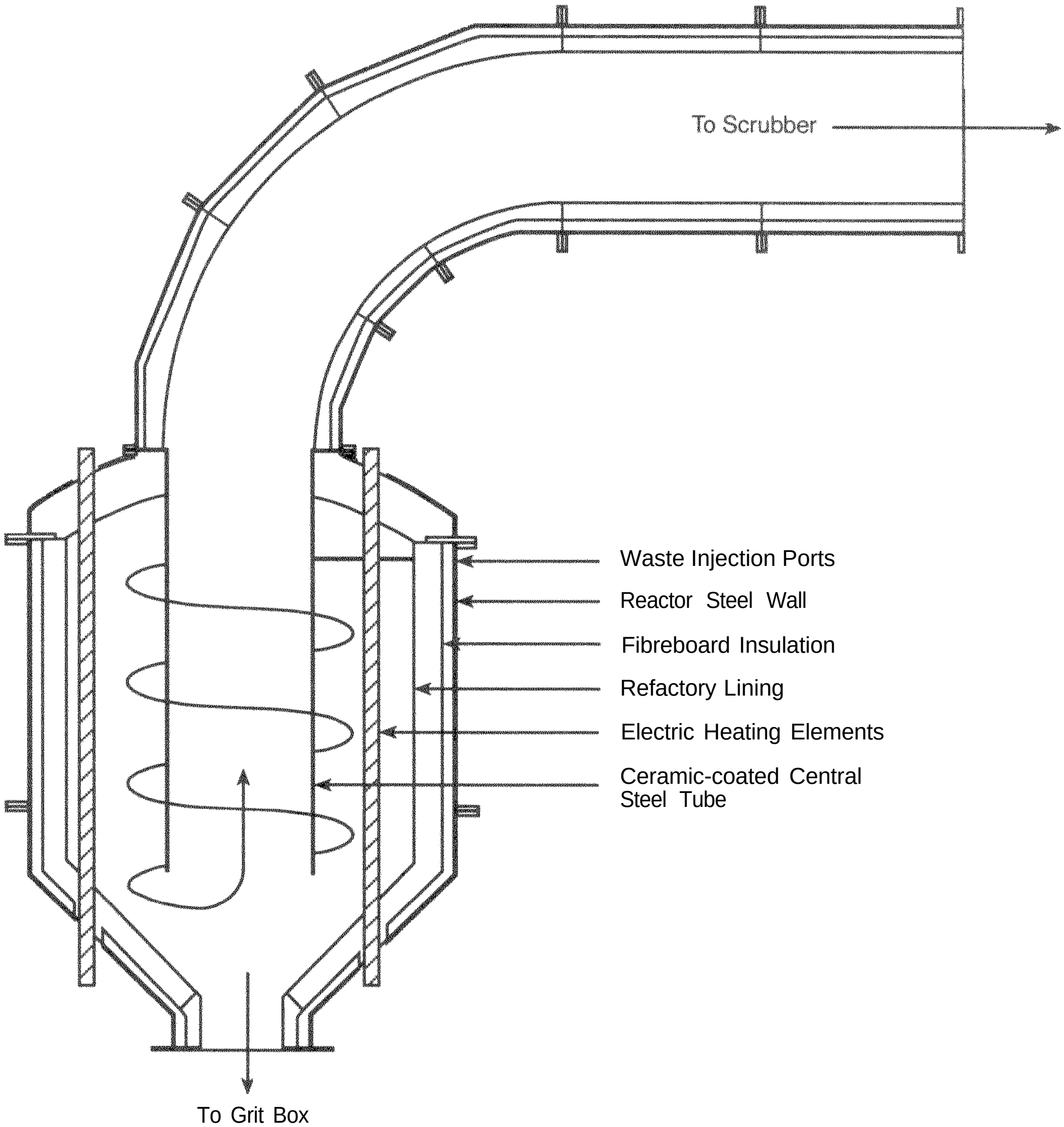


Figure 3. The EC0 LOGIC Reactor.

- Demonstrate at least 99.9999% destruction and removal efficiency (DRE) fo PCBs.
- Demonstrate at least 99.99% destruction efficiency (DE) for HCB added to the soil feed as a tracer.
- Ensure that no dioxins and furans were formed.
- Characterize product of incomplete combustion (PIC) emissions.
- Characterize hydrogen chloride emissions.
- Document compliance with Michigan Department of Natural Resources (MDNR) air permit conditions.
- Characterize criteria air pollutant emissions.
- Validate key cost assumptions used in process economic analyses.
- Characterize effluents and residual streams relative to disposal requirements.
- Determine the suitability of the reformed gases for reuse./ resale.
- Demonstrate system reliability.
- Develop a system mass balance, including metals.
- Characterize critical process scale-up parameters.
- Validate the EC0 LOGIC Chemical Ionization Mass Spectrometer (CIMS).
- Document system operation during all test runs.

Conclusions

Based on the program objectives, EPA found that the demonstration confirmed the feasibility of the gas-phase chemical reduction process for treating PCBs and other chlorinated organic compounds, producing a low Btu fuel gas from PCB-contaminated soil and providing environmentally acceptable air emissions.

The TDU did not perform to design specifications. EPA categorized the TDU test data as a system proof-of-concept rather than as a comprehensive evaluation of a fully developed unit. The test data indicated that the TDU, as presently configured, achieved desorption efficiencies at the expense of throughput. In addition, EC0 LOGIC experienced material handling problems with the TDU feed. The combination of material handling problems and inadequate organics desorption indicated a need for further development. The test data have identified system strengths and targeted areas that requite improvement.

Nevertheless, the demonstration did show that EC O LOGIC's TDU can desorb PCB contaminants. Treatment of the desorbed gas in the reactor produced stack emissions that generally met stringent regulatory levels. The reformed gas composition resembled coal-gas fuel. The scrubber liquor required either disposal as a RCRA waste or recycling through the system for additional treatment. Table 1 (Executive Summary) correlates the program conclusions with the program objectives.

Technology Evaluation

The demonstrated EC0 LOGIC TDU/Reactor Gas-Phase Chemical Reduction Process is a pilot- or small commercial-scale, trailer-mounted system, capable of treating wastewater, waste oil, and solids such as soils. The TDU demonstration (Condition 2) consisted of initial shakedown runs, a blank run to determine train capacities, and two runs on soils to test the unit's desorption capabilities. An independent AAR discusses the demonstration of the stand-alone EC0 LOGIC Reactor System (Conditions 1 and 3).

A liquid pool of waste within the Middleground Landfill provided both the liquid feedstock for the reactor process tests (Conditions 1 and 3) and the contaminated soil for the TDU tests. The Condition 2 runs treated 963 kg of soil contaminated with 627 ppm of PCBs and 14,693 ppm of HCB (Condition 2)-a tracer material used to determine DEs.

In an earlier Hamilton Harbor test, EC0 LOGIC fed sediment directly into the reactor system. However, the feed rates did not meet their expectations. For the SITE Program, they installed the TDU as a front-end to the reactor EC0 LOGIC designed it to desorb organics from soil, feed the desorbed organics to the reactor for further destruction, and then quench the treated soil prior to disposal. They employed a molten metal bath to dissolve unvaporized metals and to stabilize the metals for later disposal.

The early stages of the TDU test revealed that the system needed further engineering to improve materials handling and to correct design deficiencies. The first run processed 2.12 kg/min of contaminated soil. This was well below the 1 0 kg/min test target. Treated soil that was recovered from the TDU quench tank showed inadequate contaminant removal.

EC0 LOGIC further reduced the feed rate to 0. 4 kg/min to improve removal efficiency. Although the test results indicate that this was successful, the reduced throughput negatively affected the economic viability of the TDU configuration. EC0 LOGIC must pursue further development and testing.

organics Destruction

To determine the efficiency of organics destruction, EPA evaluated DREs, DES, benzene ring destruction, and formation of dioxins, furans, and PICs.

DRE

DRE compares the mass flow rate of selected feedstock compounds-in this case PCBs-to their mass flow rate in the boiler stack gas

$$DRE\ (\%) = (1 - Mass_{stack} / Mass_{input}) \times 100$$

Whenever possible, the evaluation based DRE calculations on actual detected values. When the value was below the detection limit for the method, input stream values were set at zero, while output streams were set at the detection limit value-the most conservative approach.

The EC0 LOGIC TDU/Reactor Process achieved 99.9999% DRE at the boiler stack. A low value (99.99%), attained by Run 2, appears anomalous, since the DRE calculated upstream of the boiler achieved the 99.9999% Toxic Substances Control Act (TSCA) criterion. Therefore, it was removed from consideration. These results show the system's potential to meet established TSCA DRE requirements, qualifying it as a possible PCB destructor. However, data at higher soil throughput are needed to ensure that adequate processing can be achieved while still maintaining at least 99.9999 % DREs for PCBs. In addition, other TSCA requirements affecting residuals, stack, and particulate emissions must also be met. The stand-alone Reactor System tests achieved a 99.9999% DRE, supporting the conclusion that a further-developed TDU/reactor system could achieve TSCA destruction efficiencies.

DE

DE is a measure of the system's ability to achieve organics destruction as measured around the system and all output streams

$$DE\ (\%) = (1 - Mass_{output} / Mass_{input}) \times 100$$

An HCB additive acted as a tracer in the feedstock for DE calculation. The program established 99.99% DE as an objective in order to compare the test results to RCRA incinerator criteria. The system achieved a 72% DE for HCB in the soil fed to the TDU for Run 1. After reducing the soil throughput, the DE improved to 99.99% (test objective for Run 2). The DE results are encouraging; they indicate that the desorption concept is workable. Once EC0 LOGIC resolves the throughput deficiency, contaminant removal from the desorbed soils should meet the 99.99% DE target.

Dioxins and Furans

The EC0 LOGIC Process reduces organics in a high-temperature hydrogen environment, as opposed to combustion by incineration in an oxygen environment. The absence of oxygen inhibits the formation of polychlorinated dibenzo-p-dioxin/polychlorinated dibenzofuran (PCDD/PCDF). Although verifying the reduction mechanisms inside the reactor was not an objective of the demonstration, the test confirmed a net destruction at the stack of trace PCDD/PCDF in the feedstock. Stack emissions registered from 0.04 to 0.14 ng/dscm for both dioxin and furan-results well within incineration regulatory guidelines. The low PCDD/PCDF stack concentrations support the conclusion that the system can effect a net PCDD/PCDF destruction, resulting in PCDD/PCDF stack emission concentrations significantly lower than current limits.

PICS

"PICs" is an incineration term not directly applicable to the EC0 LOGIC Process. The term describes a combustion system's ability to degrade feedstock organics. In a combustion system the final gaseous products are ideally water, carbon dioxide, and hydrogen chloride; other organic compounds are PICs. The EC0 LOGIC Process products are more appropriately termed products of incomplete reduction (PIRs). The process generates both PIRs during the gas-phase reactions and PICs during the reformed gas combustion phase. Both terms are used here to facilitate comparisons between the emissions from combustion devices and those from the EC0 LOGIC Process.

Incineration processes often select total hydrocarbons (THC), carbon monoxide, total PAHs, and benzene as indicators of PIC/PIR formation. For the EC0 LOGIC TDU test, the three indicators, THC, carbon monoxide, and total PAHs, were much lower than regulatory guidelines and well within the MDNR permit conditions. The THC average was 0.65 ppmv, carbon monoxide ranged from 8.2 to 13 ppmv, and average total PAH was 3.35 µg/dscm (all corrected to 7% oxygen, dry basis). Benzene emissions, ranging from 2 to 6 µg/dscm, met MDNR permit conditions. The remedial manager can expect that the EC0 LOGIC TIN/Reactor Process will meet anticipated permit limits for THC, carbon monoxide, and PAH emissions at other sites.

Air Emissions

EPA evaluated emissions of criteria air pollutants and hydrogen chloride. as well as compliance with the MDNR air permit.

Criteria Air Pollutants

During the tests, continuous emission monitors (CEMs) measured the concentrations of the criteria air pollutants at the stack: nitrogen oxides, sulfur dioxide, particulates, THC, and carbon monoxide. Each of these pollutant emission concentrations was low, well under the level established in the MDNR air permit. nitrogen oxides averages ranged from 62.9 to 69.7 ppmv; sulfur dioxide, from 1.7 to 2.2 ppmv; and particulates, from 0.13 to 0.43 mg/dscm (all corrected to 7% oxygen, dry basis). oxygen averaged 7.9% and carbon dioxide, 8.9%. The system can be expected to achieve similar results at other sites.

The demonstration-scale boiler operated between high and low fire, depending on the system's steam requirements. The test analyses showed out-of-range spike concentrations of THC and carbon monoxide (indicators of combustion efficiency) during low-fire operation, most notably in Condition 1, Run 1 (one of the liquid runs), when the boiler was cycling between high and low fire. Future users must be alert to the potential for decreased combustion efficiency and increased emissions of criteria air pollutants during low-fire operation. The boiler should be operated at firing rates and air/fuel ratios that prevent these spikes. Since the DREs were adequate in the scrubbed reformed gas, reduced combustion efficiency in the boiler will not affect the ability of the reactor process to destroy hazardous organics.

Hydrogen Chloride

The EC0 LOGIC TDU/Reactor System reduced stack hydrogen chloride emissions to below the MDNR-permitted levels. RCRA emission limits set incinerator hydrogen chloride emissions at 4 lb/hr (or less), or 99% removal. The reactor system easily achieved this; average stack concentrations were 0.68 mg/dscm at 153 mg/hr. Removal efficiencies reached 99.98%. Most of the chlorine in the feedstock accumulated in the scrubber effluent.

MDNR Permit Compliance

Table 2 compares the test results to the conditions imposed by the MDNR air permit. PCB concentrations exceeded permit limits for Run 2. However, PCB mass emissions met the permit levels. EC0 LOGIC's dissatisfaction with the TDU's desorption efficiency has already been noted.

In contrast to the reactor system tests-in which benzene stack concentrations exceeded permit limits-the TDU tests met MDNR limits. However, Condition 1 and 3 test results suggest that future users should carefully monitor/control benzene emissions; EC0 LOGIC's scale-up designs should address these areas.

Intermediate and Residual Stream Characterization

Intermediate and residual stream evaluations provided process mass balance data; intermediate process, major effluent, and miscellaneous stream characterizations; and confirmation of adherence to TSCA permit conditions. Table 3 presents the mass distribution of the waste feed and effluent streams as fractions of the total waste feed. Although the excavated site soil comprised only three-eighths of the waste feed, it contained approximately 99% of the contaminants. The three major effluent streams were the stack gas, scrubber decant, and treated soil. Most of the material in these streams entered the process as combustion air and process water. Boiler combustion air contributed most of the mass to the stack gas stream; scrubber water, to the scrubber decant stream.

Table 4 shows the concentrations of the major contaminants in the intermediate and effluent streams. These data indicate the tendency of contaminants to concentrate in the various intermediate and residual streams.

Table 2. MDNR Air Permit Conditions

Parameter	Unit	Permit limit	Condition 2 average
HCl (7% O_2, dry basis)	mg/dscm lb/hr	5.2 0.027	0.63 0.00033
THC as methane (7% O_2, dry basis)	ppmv lb/hr	200 0.19	0.65 0.00043
CO (7% O_2, dry basis)	ppmv lb/hr	100 0.15	9.75 0.00655
PCBs (dry basis)	mg/dscm lb/hr	0.09 0.00048	0.000588 2I.IE-07
Benzene (dry basis)	pgldscm lb/hr	20 0.00009	3.65 0.0000025
Chlorobenzenes as 1,2,4-trichlorobenzene (dry basis)	µg/dscm lb/hr	1 0.000002	ND <0.94 ND <5.25E-07
Opacity	%	0	N/A
Scrubber inlet temperature	°C	>35	504
Scrubber solution	PH	>8	8.4
On-line mass spectrometer	Yes/No	Yes	Yes
Reactor temperature		>850	890
Reactor pressure	in. H_2O	<IO	2.46
System oxygen	%	<0.04	0.015
Gas booster dP	in. H_2O	<16	9.16
Recirculation flow rate	cfm	100	110

ND Not detected
c Emission rate is less than the mess indicated. The mass indicated assumes that the substance is present at the detection limit

Table 3. Mass Distribution of Selected Streams

Streams		Amt. partitioned*
Input		
Wastewater	SS1	0.625
Excavated site soils	SS3	0.375
Residual/Output		
Treated soil	SS1O	0.384
Quench water	SS24	0.018
Reactor grit	SS11	0.0003
Scrubber sludge	SS12	0.003
Scrubber decant	SS13	0.564
Scrubber liquor	SS22	0.053
Stack	SS16	0.685

* g of material/kg of total feed

The test objectives included a system mass balance for metals, carbon, hydrogen, oxygen, sulfur, chlorine, and total mass. These balances were needed to evaluate system performance and to determine the fate of metals and other compounds in the feedstock.

The program established a value of $0 \pm 50\%$ (deviation from perfect closure) as the quality indicator of mass balance. Total mass balance closures ranged from +6.1 to +9.1%, indicating that data based on process mass balances (such as DRE, DE, and stack emission rates) can be considered very reliable. carbon, chloride, hydrogen, oxygen, and sulfur mass balance closures ranged from -44.9 to +98%. Only the chlorine balance (+98%) exceeded the criterion. Therefore, the elemental mass balances further support the DRE, DE, and partitioning data reliability. Closure of the metals balances, typically difficult to achieve in any system, ranged widely (from -196 to +109.6%). However, metal balance closures are of less concern than metals partitioning and their concentrations in the residual streams.

TDU Streams

The TDU test evaluated one intermediate stream-the reformed gas exiting the scrubber-and six major residual streams-cleaned soil, tin bath, quench water, reactor grit,

Table 4. Component Partitioning

Component	Run	SS3 Site soil	SS10 Treated soil	SS19 TDU exit gas[5]	SS11 Reactor grit[3]	ss12 Scrubber sludge[3]
		Streams (ppb)				
Total PCBs (mono-deca)	R1	538.000	29,200	14,700	4,400	16,400
	R2	716,000	8,260	5,690	4,400	16,400
Total PAHs	R1	24,900	ND	N/A	354,000	36,300,OOO
	R2	ND	2,400	N/A	354,000	36,300,OOO
Total PCDD/PCDF	R1	10.1	6.34	16.7	0.054	331
	R2	0.41	6.04	2.06	0.504	331
Total chlorobenzenes	R1	16.200	ND	394,000	21,700	147,000
	R2	21,900	1,100	77,400	21,700	147,000
Total chlorophenols	R1	ND	ND	15,800	28,500	194,000
	R2	ND	841	3,660	28,500	194,000
Benzene	R1	42’	ND	SAT	190	2,400
	R2	ND	5,100[2]	SAT	190	2,400
HCB	R1	6,300	4,800,OOO	74,369	3,100[1]	18,000[1]
	R2	13,000	ND	9,792	3,100[1]	18.000[1]

Component	Run	ss13 Scrubber decant[3]	ss22 Scrubber liquor	ss14 Reformed gas[5]	SS24 Quench water	SS16 Stack[5]
		Streams (ppb)				
Total PCBs (monodeca)	R1	46.1	26.2	1.26	3,220	0.08[1]
	R2	46.1	26.8	1.67	121	1.37
Total PAHs	R1	4,460	4,120	N/A	51,100	ND
	R2	4,460	3,700	N/A	414	ND
Total PCDD/PCDF	R1	0.83	0.001	0.0003	0.185	0.00014
	R2	0.83	0.001	0.00094	0.044	0.00004
Total chlorobenzenes	R1	ND	ND	ND	ND	ND
	R2	ND	ND	ND	804	ND
Total chlorophenols	R1	ND	ND	ND	ND	ND
	R2	ND	ND	ND	15.36	ND
Benzene	R1	4,900	340	SAT	240[1]	2[1]
	R2	4,900	210[2]	SAT	260[1]	6
HCB	R1	ND	ND	ND	ND	0.63[1]
	R2	ND	ND	ND	790	ND

N/A Not applicable
ND Not detected
SAT Saturated
1 Compound(s) detected at concentrations below the quantitative limit.
2 Compound detected at concentrations above linear range for analysis.
From composite sample taken over two runs.
2 Naphthalene detected at concentrations below the quantitative limit.
5 Concentration given as µg/dscm.

scrubber residuals (consisting of sludge, decant, and liquor), and stack gas emissions. The stack gas emissions have already been described.

The TDU'S capability to effectively desorb organics and dissolve volatile metals from soil affects the process's versatility. Without the TDU, the EC0 LOGIC Process can treat soil fed directly to the reactor, but feedstock size restrictions (less than l/4 in) would limit its application.

Intermediate Process Stream

Table 5 compares the reformed gas composition to several commercially available fuels. The scrubbed reformed gas is similar to blue water gas; its quality could be adequate to bum in suitable combustion equipment during commercial-scale operations. Use of the reformed gas in cogeneration or other equipment to support the remedial operation could improve the economics of large-scale applications. Although the reformed gas was of commercial quality, it would be a specialty fuel requiring burners tailored to its properties. Compressing and storing the reformed gas for resale or future use would probably be uneconomical. Unlike propane, the compressed reformed gas needs cryogenic temperatures to liquefy. Therefore, storage as a gas would require excessively large tanks.

Benzene was the most prevalent PIR in the reformed gas. Benzene concentrations exceeded the measuring capability of the sampling train. However, as shown in Table 4, the combustion step in the boiler destroys most of the residual benzene. PAH emissions from the boiler stack also were low. The reformed gas is generated from a hazardous waste, presenting

Table 5. Reformed Gas Comparison to Other Fuels

Gaseous fuels	Composition, percent by volume							
	H_2	N_2	O_2	CH_4	CO	CO_2	C_2H_4	C_6H_6
EC0 LOGIC reformed gas (average)	64.8	21.6	0.015	7.1	3.3	2.5	0.05	–
Blast furnace gas	1.0	60.0			27.5	11.5		
Blue water gas	47.3	8.3	0.7	1.3	37.0	5.4		
Carbon water gas	40.5	2.9	0.5	‘10.2	34.0	3.0	6.1	2.8
Coal gas	54.6	4.4	0.2	24.2	10.9	3.0	1.5	1.3
Coke-oven gas	46.5	8.1	0.8	32.1	6.3	2.2	3.5	0.5
Natural gas (15.8% C_2H_6)		0.8		83.4	.	..	--	.
Producer gas	14.0	50.9	0.6	3.0	28.0	4.5	--	--

Gaseous fuels	Molecular wt. of fuel lb mass/ lb mole	Higher heating value Btu/lbm	HHV Btu/scf	Sp. gr. air = 1 .O
ECO LOGIC reformed gas (average)	10.6	10,580	286	0.40
Blast furnace gas	29.6	1,170	89	1.02
Blue water gas	16.4	6,550	277	0.57
Carbon water gas	18.3	11,350	535	0.63
Coal gas	12.1	16,500	514	0.42
Coke-oven gas	13.7	17,100	603	0.47
Natural gas (15.8% C_2H_6)	18.3	24,100	1,136	0.63
Producer gas	24.7	2,470	157	0.85

MW Molecular weight
HHV Higher heating value
sp. gr. Specific gravity compared to air at 60°F

a further difficulty in its utilization as a fuel outside of the process. However, the results of the demonstration show that burning the reformed gas in combustion equipment would adequately destroy any residual hazardous organics.

Major Residual Streams

Treated soil-Since the TDU did not perform to design specifications, the treated soil did not meet TSCA nonhazardous disposal requirements. Table 4 indicates an order of magnitude improvement in the residual PCB concentrations between Runs 1 and 2. The Run 2 throughput was significantly lower than Run 1; the PCB results reflect the improved desorption resulting from increased residence time. This trend indicates that after appropriate process modifications, the treated soil might meet regulatory standards for commercial disposal.

Tin bath-The molten metal bath heats the soil to volatilize the organics; it absorbs metals and nonvolatile materials.

The program limited analytical efforts to metals analysis. The results of these analyses ranged from nondetectable levels to 380 ppm phosphorus. Eventually the tin bath will need to be reclaimed or replaced. For future applications, the remedial manager should consider the economics of this procedure.

Quench water-EC0 LOGIC designed the quench bath principally to cool the hot desorbed soils; it also operates as a soil scrubber to remove some of the contaminants not fully volatilized or absorbed in the molten metal bath.

The quench water contained 0.260 ppm benzene, 0.185 ppb PCDD/PCDF, 3.2 ppm PCBs, and 5 1.1 ppm total PAHs. It is likely that the composition of this stream will change once the TDU is fully developed and operational.

Reactor Grit-The first test run revealed that the reactor grit volume was small enough for exclusion as an effluent stream. Any accumulation can be either recycled or stored for permitted disposal after the treatment program.

Considering only PCB congeners that have three or more chlorine atoms (as defined by TSCA), the PCB concentration detected in the grit was 3.63 ppm. A congener consists of all PCB compounds having the same number of chlorine atoms but arranged in different positions for any individual congener compound. If monochlorobiphenyls, dichlorobiphenyls, and nondetected congeners (assumed to be present at the detection level) are included, the grit could contain a maximum 4.4 ppm PCB concentration. The grit also contained 354 ppm PAH, 0.19 ppm benzene, 3.1 ppm HCB, 28.5 ppm total chlorophenols, and 0.504 ppb dioxin/furan. These concentrations could affect DE if the grit is considered a process output rather than a recycled stream. However, at the commercial scale, EC0 LOGIC plans to recirculate this stream through the reactor.

Scrubber Residuals-The scrubber is a critical component in the gas-phase chemical reduction process. The scrubber effectively removes a variety of organic and metallic compounds, particulates, and chlorides. It is a key element in achieving DREs. Table 4 shows elevated levels of hazardous organic compounds in the scrubber sludge-mainly PAHs, with lesser concentrations of benzene, HCB, other chlorobenzenes, PCBs, and PCDD/PCDF. If this sludge is not recycled through the process, it must be treated as a TSCA and RCRA hazardous waste.

Based on detected PCB congeners, the PCB concentrations in the scrubber decant (46.1 ppb total) and scrubber liquor streams (26.8 ppb total) did not meet the TSCA criterion of less than 3 ppb per PCB congener in liquid residuals. For the demonstration, these streams were combined in a storage tank. Subsequent sampling by TSCA personnel confirmed that the stored liquids met the 3 ppb TSCA criterion.

If monochlorobiphenyls, dichlorobiphenyls, and nondetected congeners (assumed to be present at the detection level) are included, the scrubber decant could contain maximum PCB concentrations up to 46 ppb; the scrubber liquor could contain maximum PCB concentrations up to 26.8. The scrubber decant also contained 4.46 ppm PAHs and 4.9 ppm benzene. The scrubber liquor contained up to 4.1 ppm PAHs and 0.340 ppm benzene. If these streams are not recycled through the process, they will require further treatment as a RCRA waste.

The scrubber residuals did not contain detectable levels of chlorobenzenes or chlorophenols. Chlorobenzenes and chlorophenols appeared only in the scrubber sludge.

Miscellaneous Streams

The demonstration team collected water that came in contact with the processing equipment, such as wash and rinse water from equipment decontamination, and stored it apart from other wastes, disposing of it as a hazardous waste. The treatment/disposal of this wash/rinse water is site-specific.

TSCA Permit Conditions

The program required that EC0 LOGIC obtain a TSCA research and development permit. The permit conditions addressed PCB throughput and PCB concentrations in the effluent streams. TSCA established maximum PCB levels of 2 ppm per congener in soil and 3 ppb per congener in water streams. TSCA evaluated the combined scrubber liquid residual streams based on samples from the storage tanks. These samples met the criterion that allowed disposal in a commercial treatment system. However, the local publicly owned treatment works (POTW) imposed stricter PCB effluent concentrations than those permitted by TSCA, requiring disposal of the liquid residuals through a RCRA-permitted facility. Since POTWs set their acceptance requirements based on their effluent requirements, acceptance/rejection of the scrubber liquid streams will be site-specific. In order for the EC0 LOGIC system to process PCB materials, a TSCA permit will be required. The remedial manager should formulate a schedule that includes obtaining a TSCA permit and addressing any process and operating constraints that the permit may impose.

Equipment and Operating Considerations

The remedial manager considering the use of the EC0 LOGIC TDU should understand the functions of the major equipment components and potential operating problems associated with them.

System Components

The principal components of the TDU system are its material handling systems and its proprietary internal components. More data on the proprietary elements will be available to future users once EC0 LOGIC develops and commercializes the TDU.

Material Handling System-For the demonstration, the material handling systems consisted of a feed conveyor, a feed hopper, a feed screw, and a treated soil drag chain. Blockages in the TDU feed hopper impeded operations. EC0 LOGIC resorted to both forcing feed through the hopper and removing the feed screw to free blocked material. Inefficient feed operations resulted in significantly reduced feed rates. Material handling considerations (as with almost any system) can affect system performance and costs. Adding various soil pretreatment steps (size reduction, classification, etc.) might prevent these material handling problems.

TDU Internal Components--The TDU design is proprietary. The reduced demonstration throughput resulted from feed hopper restrictions and internal TDU operations. ECO LOGIC is currently modifying both systems to improve throughput.

System Reliability

The program evaluated system reliability during processing. The TDU test was designed to treat I9 tons of material-only 1. 1 tons were processed. The reliability has been expressed in terms of percent of rated capacity-actual throughput (2.12 kg/min) compared to planned throughput (10 kg/min). This translates to a 21% reliability.

In addition, the test plan had specified three replicate runs, but only two runs were completed because of TSCA permit restrictions. System availability-the number of planned test days compared to the actual test days for the entire system (TDU and TDU/reactor)-measured 24%.

Scale-Up Parameters

One program objective sought to identify the critical process scale-up parameters. Knowing these parameters assists future users in evaluating a proposed commercial-size operation. The TDU's molten bath temperature and contaminant residence time are the critical parameters for efficient desotption.

CIMS Validation

The CIMS is the primary process control unit for the TDU/ reactor system. It records and stores data. It measures selected compounds and their desorption products to maximize organic destruction. Demonstration results show that the CIMS may reflect data trends useful for process control but is not, at this stage of its development, a reliable source of quantitative data. Further testing will determine whether the CIMS can provide adequate process control.

System Operating Conditions

Automatic computer data and manual logs documented process operating conditions and the status of the operating components. These data clarified process results and documented compliance with permit conditions. Table 6 lists the averages for several key system parameters; the TER contains further details.

Technology Applicability

This section discusses the applicability of the technology relative to the site, waste media, safety, and staffing.

Site Characteristics

The EC0 LOGIC system requires a fairly level area, approximately 120 ft x I80 ft, for the processing and auxiliary equipment. Utility tanks require level surfaces or supports. Except for process gas tank support pads, no additional surface support is needed. The reactor system equipment sits on two mobile trailers; a separate trailer transports the TDU, solid feed hopper, and quench system.

Cold-weather operations may inhibit efficient destruction because of the incremental amount of energy required to heat the reactor and the TDU molten metal bath. In addition, feedstock liquids would require melting prior to treatment; liquid residuals could freeze in the unheated storage tanks. Winterization, including heat-tracing, is necessary to provide adequate feedstock and to ensure unintetrupted processing.

Applicable Media

Initially, EC0 LOGIC designed the reactor system to process liquids, with soil processing limited to about 30% solids.' EC0 LOGIC added the TDU to gain greater feedstock processing capabilities.

Table 6. Summary of TDU Operating Conditions

System Component	Parameter	Run 1	Run 2
Bath	Temperature (°C)	616	632
Air Space	Temperature (°C)	614	610
Combustion Gas	Temperature (°C)	662	653
Exhaust Gas	Temperature (°C)	396	500
Pressure	in. H_2O	2.0	2.5
Soil	Feed Rate (kg/min)	2.12	0.40
HCB	Feed Rate	16.6	9.67

Without the TDU, the reactor system can process soil fed directly to the reactor. EC0 LOGIC reports that they can process soil sized l/4 inch or less. However, the demonstration did not test this approach. EC0 LOGIC decided, instead, to test the soil treatment capabilities of the TDU, designed to process 25 tons/day. The demonstration TDU throughput reached about 1.1 tons. Data from the TDU Demonstration are contained in the TER.

The reactor system is best suited for processing liquids and TDU off-gases/water vapor. The waste's organic content limits the demonstration-scale system's feed rate because of reformed gas generation. Currently, EC0 LOGIC plans to improve throughput by storing excess reformed gas after compressing it. Future users should consider the implications, logistics, and costs of this approach.

Safety Considerations

The principal safety considerations for the EC0 LOGIC Process concern personnel, chemical use, equipment integrity, and process control.

Personnel Safety

The components of personnel safety requiring attention are those associated with Construction Safety Standards [29 CFR 19261 addressing such topics as slips, trips, and falls; confined space entry; contingency planning; etc. The regulations in 29 CFR 1910.120 address personal protective equipment (PPE). High voltage electrical equipment standards are also a concem.

Chemical Use

The chemical hazards of the EC0 LOGIC Process accompany the use of propane, liquefied nitrogen/oxygen, hydrogen, industrial chemicals, and hazardous feed material. In addition, the process generates methane. Standardized industrial procedures provide guidance for storing, transporting, and handling these materials.

There should be no undue concern associated with hydrogen use in the process. Well established and proven procedures are available for safe hydrogen storage and use. Hydrogen is no more nor less dangerous than gasoline or methane. As with these substances, hydrogen must be handled with due regard for its unique properties.

The electrical, petroleum refining, chemical, petrochemical, and synthetic fuel industries have safely used hydrogen in large quantities for decades. Through much of the last century Europe successfully used hydrogen-enriched gases (coal gas, town gas, producer gas) to satisfy residential fuel needs.[2] The Northeast United States used coal gas until the late 1950s.

For the demonstration, EC0 LOGIC developed a Hydrogen Safety Procedure based on the Canadian National Research Council's Safety Guide for Hydrogen.[2] Ultimately, remedial managers must assure themselves that the flammable gases used in the EC0 LOGIC Process are handled, stored, and used in accordance with industry standards and guidelines.

Equipment Integrity

Verification of system component integrity is essential to process safety. The remedial contractor should undertake pressure testing, hydrostatic testing, and metal embrittlement evaluations. The results should be certified before processing hazardous materials. Hydrogen is more difficult to contain than other gases because of its small molecular size. Therefore, interfaces of equipment, instruments, and piping must be leak-free. To provide an additional safeguard, EC0 LOGIC maintains the system under slight positive pressure, preventing infiltrattion of oxygen. As a safety backup, EC0 LOGIC monitors internal oxygen levels and maintains gas feeds (propane and hydrogen) at low pressure to prevent pipeline breaks.

Process Safety System

EC0 LOGIC designed a safety system to immediately react, should any system upset occur. The control system initiates system shutdown in response to high oxygen content, high pressure drop across the circulating fan, scrubber pump failure, ground faults, boiler failure, high hydrocarbon emissions, or power failure. However, these shutdown systems were not needed during the demonstration.

Whenever process conditions require a system shutdown, the system program stops the waste input streams and replaces them with clean steam to prevent any negative pressure in the reactor. The program also stops hydrogen flow and introduces a nitrogen purge. The TDU waste feed stops, but the drag chain continues to operate. The hydrogen flow above the molten bath halts; a nitrogen purge replaces it. Reformed gas flow to the boiler stops. Either an operator or an automatic computerized process controller initiates these events.

Staffing Issues

The CIMS system facilitates monitoring and remote adjustment of process parameters. This reduces labor requirements for monitoring and maintenance personnel. The monitoring personnel must be capable of evaluating system problems and directing maintenance personnel in problem resolution. Since operations can be controlled remotely, only those personnel needing to manually adjust or maintain the system components require PPE. Since the system will be processing hazardous substances, the medical monitoring, training, and personal protection requirements of 29 CFR 1910.120 will remain in effect.

Regulatory Considerations

Several pieces of federal legislation and any state or local laws present compliance considerations in operating the EC0 LOGIC System.

Clean Air Act

The Clean Air Act (CAA) establishes primary and secondary ambient air quality standards to protect public health; it also sets emission limits for hazardous air pollutants. Each state administers its own permitting requirements as part of the State Implementation Plan developed to bring the state into compliance with National Ambient Air Quality Standards (NAAQS). These standards apply to the EC0 LOGIC Process because of its potential emissions. The process will probably require an air permit to operate at any site, whether or not the state has attained its NAAQS. Even if the area is in attainment, Prevention of significant deterioration regulations may further curtail emissions. Regulatory requirements must be determined on a site-by-site basis.

Clean Water Act

The Clean Water Act (CWA) regulates direct discharges to surface water through the National Pollutant Discharge Elimination System (NPDES). These regulations require that wastewater point-source discharges meet established water quality standards. The EC0 LOGIC Process generates noncontact and contact water discharges. Noncontact water sources include the heat exchanger, evaporative cooler, boiler water, and blow-down. Contact water comes from the TDU quench, scrubber liquor, tank cleaning, and equipment wash down; it will likely require further treatment prior to discharge to a POTW. In any case, wastewater discharge to a sanitary sewer requires a discharge permit or, at least, concurrence from state and local regulatory authorities that the wastewater is in compliance with regulatory limits.

Comprehensive Environmental Response, Compensation, and Liability Act

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. amended 'by SARA of 1986, provides federal funding to respond to releases of hazardous substances to air, water, and land. Section 121 of SARA, entitled, "Cleanup Standards" states a strong statutory preference for remedies that are highly reliable and provide long-term protection. It recommends that remedial action utilize on-site treatment that ". .. permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances." In addition, remedial actions must consider the technology's long-term and short-term effectiveness, implementability, and cost.

EPA employed the TDU Demonstration only as a proof-of-concept; the TDU requires further development to successfully handle contaminated solids. Based on this conclusion, further development must take place before the TDU's capability to meet CERCLA requirements can be evaluated.

Occupational Safety and Health Act

Sections 1900 to 1926 of the Occupational Safety and Health Act (OSHA) govern EC0 LOGIC remedial operations: 1910.120 for hazardous waste. operations, 1926 for construction site activities, and 1910.1200 for worker and community right-to-know.

Resource Conservation and Recovery Act

RCRA is the primary federal legislation governing hazardous waste activities. RCRA Subtitle C contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are applicable to CERCLA activities.

Depending on the waste feed and the effectiveness of the treatment, the EC0 LOGIC TDU/Reactor Process generates three potentially hazardous waste streams: the scrubber liquor, the TDU quench water, and the treated soil. To generate these wastes, the remedial manager must obtain an EPA generator identification number and either comply with generator accumulation and storage requirements under 40 CFR 262, or receive a Part B Treatment, Storage, and Disposal (TSD) interim status permit. CERCLA mandates compliance with RCRA TSD requirements. A hazardous waste manifest must accompany off-site waste shipment; transport must comply with Federal Department of Transportation (DOT) hazardous waste transportation regulations. The receiving TSD facility must hold a permit and comply with RCRA standards.

Technology or treatment standards apply to many hazardous wastes; those appropriate for the EC0 LOGIC Process depend on the waste generated. RCRA land disposal restrictions, 40 CFR 268, mandate hazardous waste treatment after removal from a contaminated site and prior to land disposal, unless a variance has been granted. The scrubber liquor, quench water, and/or treated soil will require additional treatment prior to land disposal, if they do not meet their pertinent treatment standards.

Toxic Substances Control Act

The EC0 LOGIC Process treats wastes containing PCBs. Therefore, the remedial manager must address TSCA standards for PCB spill cleanups and disposal. The EPA document, CERCLA Compliance with Other Laws Manual,[3] discusses TSCA as it pertains to Superfund actions.

If EC0 LOGIC plans to treat PCB-contaminated material containing no RCRA wastes, they must obtain a TSCA authorization. The conditions of this authorization may contain operational, throughput, or disposal constraints that could affect treatment efficiency and costs. If EC0 LOGIC chooses to treat PCB-contaminated material containing RCRA wastes, a RCRA permit for a TSD facility will also be required.

State and Local Regulations

Compliance with applicable or relevant and appropriate requirements (ARARs) may require meeting state standards that are mote stringent than federal standards; state standards may control non-CERCLA treatment activities. Several types of state and local regulations affect operation of the EC0 LOGIC Process, such as, permitting requirements for construction/ operation, prohibitions on emission levels, and nuisance rules.

References

1. U.S. Office of Technology Assessment, "Dioxin Treatment Technologies" (background paper), OTA-BP-0-93, U.S. Government Printing Office, Washington, D.C., November 1991.

2. Kalyanam, K. M., and Hay, D. R., Safety Guide for Hydrogen, National Research Council of Canada, Ottawa, Ontario, 1987.

3. U.S. EPA. CERCLA Compliance with Other Laws Manual Part II: Clean Air Act and Other Environmental Statutes and State Requirements, Interim Final, EPA/540/G-89/009, OSWER, Washington, D.C., August 1989.

Section 4
Economic Analysis

Introduction

Estimating the cost of employing an innovative technology is a major objective in each SITE demonstration project. This economic analysis presents data on the costs (excluding profit) for a commercial-scale remediation using the EC0 LOGIC Gas-Phase Chemical Reduction Process. With a realistic understanding of the test costs, it should be possible to forecast the economics of operating similarly sized systems or to extrapolate these figures for larger systems at other sites.

The SITE Demonstration of the EC0 LOGIC TDU/ Reactor System conducted at the Middleground Landfill treated PCB-contaminated soil. The demonstration achieved an average system feed rate of 1.26 kg/min. Target rates for the test runs were significantly more than the average rate actually achieved. This economic analysis extrapolated the demonstration data to commercial feed quantities, assumed at 300 tons of soil, based on the ratios of wastewater, oil, and soil actually treated during the demonstration.

Since the process would experience some downtime, three different utilization factors have been presented: 60%, 70%, and 80%. Certain cost elements were fixed; others were time-sensitive.

Because the testing of the stand-alone reactor system and the combined TDU/reactor system were concurrent, actual cost data could not be completely isolated. However, financial analysis allowed the extrapolation of data to provide for the addition of the TDU.

Decreased process efficiency (lower utilization factor) would require an extended time to process the same amount of material, reflecting higher costs. Final figures have been expressed as cost (1994 U.S. dollars) of material processed.

Conclusions

Previous demonstration data, reported in an independent AAR, showed the commercial-scale EC0 LOGIC Reactor Process to be an acceptable remedial alternative for liquids contaminated with PCBs. Since the process was effective in treating the PCB-contaminated Middleground Landfill liquids and soils, it should be applicable to the remediation of other similar sites.

The TDU/reactor process demonstration was, as explained earlier, a proof-of-concept test. The results of the two runs in Condition 2 showed a need for further development of the TDU. The incremental TDU treatment costs (1994 U.S. dollars) ranged from a low of $5OO/ton to a high of $630/ton, depending on the utilization factor. Because of limited data, the cost estimates presented in this analysis may range in accuracy from +50% to -30%. an order of magnitude guideline **suggested** by the American Association of Cost Engineers.

The cost effectiveness of employing a TDU in conjunction with the EC0 LOGIC Reactor Process cannot be assured without further development and demonstration.

Issues and Assumptions

The costs associated with this technology were calculated on the basis of demonstration parameters such as the following:

- A small to medium hazardous waste site.
- One ton of soil feed.
- A short treatment period during the SITE Demonstration.

While the equipment used for the demonstration was a small commercial size, it may not be applicable where time constraints require increased capacity. The targeted test throughput rates were considerably higher then those actually realized during the demonstration. Variations in throughput could significantly affect costs.

The reactor system, described in an independent AAR, treated the desorbed gases from the TDU. This economic analysis addresses only those costs associated with the soil feed processed through the TDU.

Important assumptions regarding specific operating conditions and task responsibilities, described below, will impact cost estimates.

Site-Specific Factors

The demonstration site presented certain site-specific characteristics that affected the cost estimate. Variations to these characteristics may improve or worsen the project economics:

* Proximity to utilities, with capacity sufficient to service project
* Favorable ambient conditions
* Clear, level work area
* Small, specialized project with minimal requirements for storage, administration, services, etc.

Fixed costs are not related to time or volume, nor are they affected by project magnitude. Such costs include the transportation/setup/removal of trailers, sanitary facilities, decontamination facilities, process equipment, foundations, roads, and utilities. In employing the results of this SITE economic analysis to forecast a unit cost ($/ton), the potential user should recognize that these same fixed costs spread over larger volumes of contaminated material would lower the unit cost. The reverse would be true of a smaller project.

Costs Excluded from the Estimate

Although the SITE Program provides 12-iatm list of costs on which the economic analysis of a demonstration should be calculated, not all 12 apply to every project. Certain cost items were excluded from this analysis because they were either site-specific, project-specific, or the obligation of the site owner/responsible party.

Basis for Economic Analysis

To provide a basis of cost effectiveness comparison among technologies, the SITE Program links costs to 12 standard categories listed below:

Site preparation
Permitting and regulatory
Capital equipment
Mobilization and start-up
Operations labor
Supplies
Utilities
Effluents
Residuals
Analytical
Repair and maintenance
Demobilization

The cost estimates are representative of charges assessed to the client by the vendor but do not include profit.

Some of the cost categories do not apply to this analysis because they are site-specific, project-specific, or the obligation of the site owner/responsible party:

- Project engineering and design, specifications, requisitions
- Permits, regulatory requirements, plans
- Wells, pipelines, excavation/stockpiling/handling of waste (except for feed to process equipment),
- Backfilling, landscaping, any major site restoration
- Sampling and chemical analysis except as required for disposal of miscellaneous effluents and wastes
- Initiation of monitoring programs
- Post-treatment reports, regulatory compliance

Wherever possible, applicable information has been provided on these excluded costs so that potential users may calculate site-specific economic data for their projects.

The TDU costs associated with the standard categories listed below reflect only the incremental costs for the TDU component of the combined TDU/reactor system. These costs are shown in Table 7.

Site preparation	foundations for TDU and material handling equipment.
Capital equipment	TDU (and its internal components) conveyors feed hopper quench tank

[equipment costs have been annualized based on the formula below:]

$$A = C\frac{i(1+i)^n}{(1+i)^n - 1}$$

A – annualized cost, $
C – capitalized cost, $
i – interest rate, 6%
n – useful life, 10 years

Mobilization/ start-up	delivery taxes insurance	working capital equipment setup trial bum
Operations labor	one technician per shift	
Supplies	propane	
Utilities	electric usage (mechanical equipment)	
Repairs and maintenance	$150/mo allowance	
Demobilization	dismantling equipment preparation for shipment demolishing foundations	

Results of Economic Analysis

The largest single cost component of this treatment technology was the cost of TDU fuel-accounting for 67% of the total treatment cost at 80% utilization. Labor comprise d capital equipment, 11%. The remaining categories comprised only 13% of the total treatment cost. Assuming that the throughput had achieved test target rates, the incremental costs per ton would be less than $100.

Table 7. Economic Analysis for the EC0 LOGIC TDU System

Activity	Utilization 60% (250 days)	70"%, (214 days)	**80% (188 days)**
Site preparation	2,600	2,600	2,600
Capital equipment	20,000	18,000	16,000
Start-up/mobilization	5,000	5,000	5,000
Labor	50,000	22,000	13,800
Supplies	100,000	100,000	100,000
Utilities	8,500	8,500	8,500
Maintenance costs	1,200	1,000	900
Demobilization	2,000	2,000	2,000
Totals	**189,300**	**159,100**	**149,800**
costs	$630/ton	$530/ton	$500/ton

References

1. Richardson Engineering Services ***Cost Estimating Guide,*** Vol 1, 1993 edition.

2 R. S. Means. "General Building Construction," ***Cost 'Esti. mating Services.***

3. Evans, G. M. "Estimating Innovative Technology Costs for the SITE Program." EPA/RREL for ***Journal of Air Waste Management Association.*** July, 1990. Volume 40, No. 7.

Appendix A
Demonstration Sampling and Analysis

Introduction

The EC0 LOGIC Reactor System SITE Demonstration consisted of two test conditions with three runs each. Condition 1 treated PCB-contaminated wastewater; Condition 3, PCB-contaminated waste oil. The TDU demonstration comprising Condition 2 processed contaminated soil-the subject of an independent AAR.

Sampling and analysis of the feedstock, intermediate streams, and residuals followed the procedures outlined in the demonstration plan. EPA subjected the entire sampling and analysis program to a rigorous Category II Quality Assurance (QA) procedure designed to generate reliable test data. The demonstration plan also contains the QA procedure. The TER presents a detailed account of the demonstration results.

Figure A-l shows the sampling locations. An SS designation represents EPA contractor sampling locations shown in Table A-l ; MS indicates an EC0 LOGIC Process monitoring station, listed in Table A-2.

Methodologies

The EPA program sampled three matrices: gases, liquids, and solids. EPA sampled and analyzed all key input and output streams; they selected intermediate streams for physical properties (flow rate, density, moisture), PCBs, PCDD/PCDF, PAHs, PCE, chlorobenzenes, chlorophenols, VOCs, 13 trace metals, hydrogen chloride, oxygen, carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen oxides, THC, and other selected compounds. Tables A-3, A-4, and A-5 list the sampling and analysis methods used by EPA. The demonstration plan and TER contain further details about the Sampling and Analysis Program.

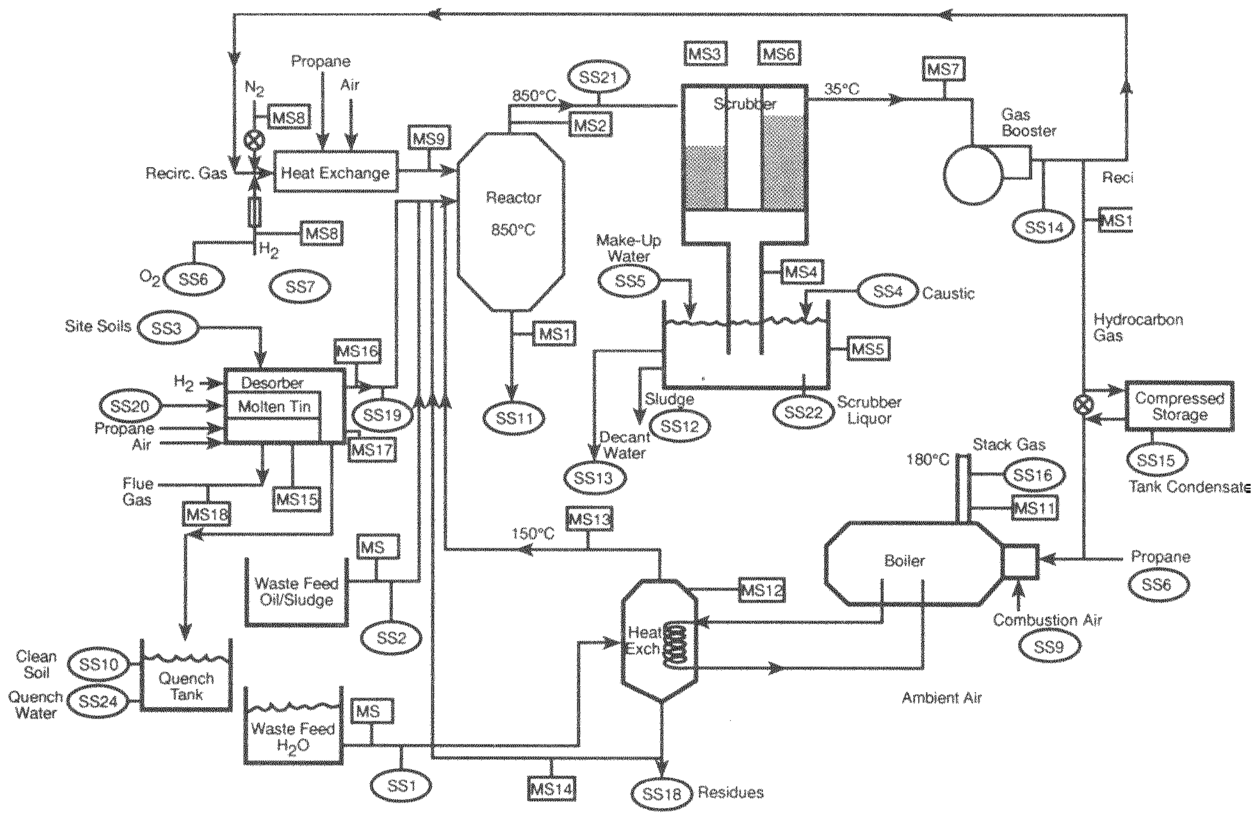


Figure A-l. Sampling and monitoring stations.

Table A-l. EPA Sample Locations

Stream	Description	Location
SSl	Wastewater	Feed line before pump
SS2	Waste oil	Oil drum
SS3	Contaminated soil	Feed drum
SS4	Caustic soda	Caustic soda reservoir tank
SS5	Scrubber makeup water	Feed line
SS6	Propane	Feed line
SS7	Hydrogen	Feed line
SS9	Combustion air	Boiler inlet
SSl0	Treated soil	Treated soil collection drum
SS11	Reactor grit	Reactor grit catchpot
ss12	Scrubber sludge	Scrubber effluent tank
ss13	Scrubber decant	Scrubber effluent tank
ss14	Reformed gas	Duct after gas booster fan
SS15	Tank condensate	Bottom of condenser
SS16	Stack gas	Boiler stack
SS18	Heat exchanger	Heat exchanger residue waste drum
SS19	TDU gas	TDU-to-reactor feed line
SS20	TDU molten bath	Bath vessel
SS22	Scrubber liquor	Scrubber tank
SS24	Quench water	Quench water tank

Table A-2. EC0 LOGIC Process Control Monitoring Stations

Parameter	Stations	Frequency	Method
Temperature	2,3,4,5,6,7,9, 11, 12, 13, 15, 16, 17.18	Continuous	Thermocouple
Pressure	12. 13, 16, 1.4,7 7, 10	Continuous Continuous l/2 hour	Pressure transmitter Differential pressure transmitter Gauge
Flow rate	7, 10 13 8	Continuous Continuous Hourly	Differential pressure transmitter Vortex flow meter Orifice meter
Feed rate	13 14	Hourly l/2 hour	Vortex flow meter Tracer injection
PH	5	Continuous	pH meter
Gas constituents	7	Continuous	0_2 analyzer; CIMS

Table A-3. Flue Gas Sampling and Analytical Methods

Analyte	Sampling Principle	Reference	Analytical Principle	Reference
PCBs	XAD-2	Method 0010*	HR GC/HR MS	EPA 680*
Dioxins/furans	XAD-2	Method 0010	HR GC/HR MS	EPA 23**
PAHs	XAD-2	Method 0010	GC/MS	EPA
CB/CP	XAD-2	Method 0010*	GC/MS	EPA 8270*
Volatile organics	Tenax	Method 0030*	GC/MS	EPA 5041*
Metals	Impinger	EPA Method 29 (draft)	CVAAS, ICAP, GFAAS	EPA 29 (draft)
HCI	Impinger	EPA Method 26**	IC	EPA 26**
Particulates	Filter	EPA Method 5**	Gravimetric	EPA 5**
NO_x	CEMS	EPA Method 7E**	Chemiluminescence	EPA 7E**
SO_2	CEMS	EPA Method 6C**	NDUV	EPA 6C**
O_2	CEMS	EPA Method 3A**	Paramagnetic	EPA 3A**
CO_2	CEMS	EPA Method 3A**	NDIR	EPA 3A**
CO	CEMS	EPA Method 10**	NDIR	EPA 10**
THC	CEMS	EPA Method 25A**	FID	EPA 25A**
Fixed gases	Tedlar bag	EPA Method 18"	GC	MASA 133***
Sulfur compounds	Tedlar bag	EPA Method 18**	GC/FPD	EPA 15**
Heating value	Tedlar bag	EPA Method 18"	GC	ASTM 2620M

* *Test Methods for Evaluating Solid Wastes, SW-646,* U.S. EPA (November 1966. reissued July 1992 and November 1992).

** Code of *Federal Regulations,* 40 CFR 60.

*** Lodge, J.P., Methods of *Air Sampling and Analysis.* 3rd Edition, Lewis Publishers, Inc., Chelsea. MI, 1969.

Table A-4. Solids Sampling and Analytical Methods'

Analyte	Analytical Principle	Reference
PCBs	GC/MS	EPA 680*
Dioxins/furans	HR GC/HR MS	EPA 8290*
CB/CP	GC/MS	EPA 8270*
PAHs	GC/MS	EPA 8270*
Volatile organics	GC/MS	EPA 8260*
Metals	CVAAS, AAS, ICAP	EPA 6010, 7471*
Organic halogens	IC	EPA 9020*
Inorganic halogens	IC	ASTM E776
Hexavalent chromium	Calorimetric	EPA 7196*
Total sulfur	Gravimetric	ASTM D3177
TCLP volatiles	GC/MS	EPA 8240*
TCLP metals	CVAAS, ICAP	EPA 6010,747O*
Ash	Combustion/gravimetric	ASTM D482
Heating value	Bomb calorimeter	ASTM D240
Ultimate analysis	Combustion	ASTM D3176
Total organic carbon	GC	EPA 9060*
Density	Hydrometer	ASTM D1298

* Usina arab samples. oerformed in accordance with U.S. EPA Office of Solid Waste document *Test Methods for Evaluating Solid Wastes,* SW-846, 3rd Edition, Volume II, Chapter 9, November 1966.

Table A-5. Liquids Sampling and Analytical Methods

Analyte	Analytical Principle	Reference
PCBs	GC/MS	EPA 680*
Dioxins/furans	HR GC/HR MS	EPA 8290*
CB/CP	GC/MS	EPA 8270*
PAHs	GC/MS	EPA 8270'*
Volatile organics	GC/MS	EPA 8260*
Metals	CVAAS, ICAP	EPA 6010,747O*
Organic halogens	IC	EPA 9020*
Inorganic halogens	IC	EPA 325.2
Hexavalent chromium	Calorimetric	EPA 7196*
Total'sulfur	ICAP	EPA 6010*
TCLP volatiles	GC/MS	EPA 8240
TCLP metals	CVAAS, ICAP	EPA 6010.7470*
Ash	Combustion/gravimetric	EPA 160.4
Heating value	Bomb calorimeter	ASTM 0240
Ultimate analysis	Combustion	ASTM D3176
Total organic carbon	GC	EPA 9060*
Density	Hydrometer	ASTM D1298
PH	pH meter	EPA 9040*

* Using grab samples, performed in accordance with U.S. EPA Office of Solid Waste document *Test Methods for Evaluating Solid Wastes,* SW-846, 3rd Edition, Volume II, Chapter 9. November 1966.

Appendix B
Vendor's Claims

Introduction

Following the 1992 SITE Demonstration of the ECO LOGIC Gas-Phase Chemical Reduction Process in Bay City, Michigan, several advancements have been made. Further research and development has focused on optimizing the process for commercial operations, and improving the design of the soil/ sediment processing unit. These advancements along with relevant background information are described herein.

Since 1986, ECO LOGIC has been conducting research with the aim of developing a new technology for destroying aqueous organic wastes, such as contaminated harbor sediments, landfill soil and leachates, and lagoon sludges. The goal was a commercially viable chemical process that could deal with these watery wastes and also process stored wastes (e.g. contaminated soils, solvents, oils, industrial wastes, pesticides and chemical warfare agents). Other companies and agencies at that time were focusing their efforts primarily on incineration and were investigating a variety of predestruction cleaning or dewatering processes to deal with the problem of aqueous wastes. The process described in this paper was developed with a view to avoiding the expense and technical drawbacks of incinerators, while still providing high destruction efficiencies and waste volume capabilities.

Following bench-scale testing supported by the National Research Council, a lab-scale process unit was constructed in 1988 and tested extensively. Based on the results of these tests, a mobile pilot-scale unit was constructed with funding support from the Canadian Department of National Defence. The pilot-scale plant was completed and commissioned in 1991. It was taken through a preliminary round of tests at Hamilton Harbor, Ontario, where the waste processed was coal-tar-contaminated harbor sediment. That demonstration received funding from both Environment Canada's Contaminated Sediment Treatment Technology Evaluation Program and the Ontario Ministry of Environment's Environmental Technologies Program. In 1992, the same unit was taken through a second round of tests as part of the EPA SITE program in Bay City, Michigan. This demonstration was partially funded by the Environment Canada Development and Demonstration of Site Remediation Technology Program, the Ontario Ministry of Energy and Environment Environmental Technologies Program and the Canadian Department of National Defense Industrial Research Program. In this test program, the pilot-scale unit processed PCBs in aqueous, organic, and soil matrices. This paper describes the process, the commercial-scale system under construction, and the results of demonstration testing in Canada and the United States.

Process Chemistry

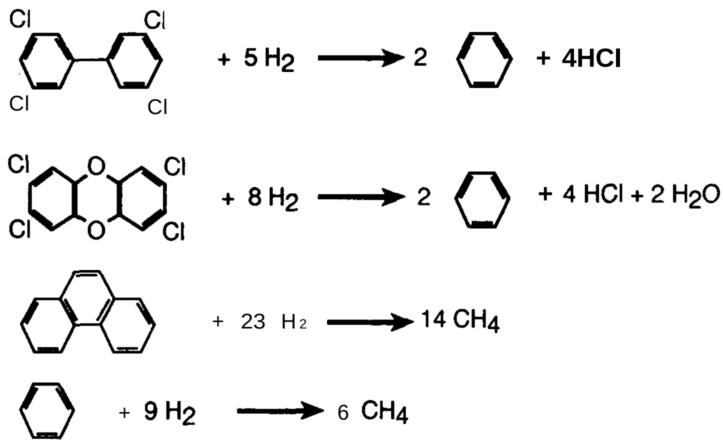
The process involves the gas-phase reduction of organic compounds by hydrogen at temperatures of 850°C or higher. Chlorinated hydrocarbons, such as PCBs, and polychlorinated dibenzo-p-dioxins (dioxins), are chemically reduced to methane and hydrogen chloride, while non-chlorinated organic contaminants, such as PAHs, are reduced substantially to methane and minor amounts of other light hydrocarbons. The hydrogen chloride produced can be recovered as acid or scrubbed out in a caustic scrubber downstream of the process reactor.

Figure B-l shows some of the reduction reactions, including intermediate steps, for the destruction of a variety of contaminants using the ECO LOGIC Process. Unlike oxidation reactions, the efficiency of these reduction reactions is enhanced by the presence of water, which acts as a reducing agent and a source of hydrogen. The water shift reactions shown produce hydrogen, carbon monoxide, and carbon dioxide from methane and water. These reactions can be used at higher efficiencies by subjecting scrubbed methane-rich product gas to catalytic steam reforming, reducing the requirements for purchased hydrogen.

A benefit of using an actively reducing hydrogen atmosphere for the destruction of chlorinated organic compounds, such as PCBs, is that no formation of dioxins or furans occurs. Any dioxins or furans in the waste are also destroyed effectively. The reducing hydrogen atmosphere is maintained at more than 50% hydrogen (dry basis) to prevent formation of PAHs. This makes the scrubbed recirculation gas suitable for continuous monitoring using an on-line CIMS. By measuring the concentrations of intermediate reduction products, the CIMS produces a continuous indication of destruction efficiency.

SE25 Commercial-Scale Process Unit

Figure B-2 is a schematic of the reactor where the destruction of the waste takes place. The various input streams are injected through several ports mounted tangentially near the top of the reactor. Special nozzles are used to atomize liquid



PCB molecule and hydrogen react to produce benzene and hydrogen chloride

Dioxin molecule and'hydrogen react to produce benzene, hydrogen chloride, and water

PAH molecule and hydrogen react to produce methane

Benzene and hydrogen react to produce methane

$C_n H_{(2n+2)} + (n-1) H_2 \longrightarrow n\, CH_4$

Hydrocarbons and hydrogen react to produce methane

Water Shift Reactions

$CH_4 + H_2O \longrightarrow CO + 3H_2$

Methane and water react to produce carbon monoxide and hydrogen

$CO + H_2O \longrightarrow CO_2 + H_2$

Carbon monoxide and water react to produce carbon dioxide and hydrogen

Figure **B-1.** **EC0 LOGIC Process reactions.**

wastes to **accelerate** liquid vaporization. The gas mixture swirls around a central stainless steel tube and is heated by 18 vertical radiant tube heaters with internal electric heating elements. By the time it reaches the bottom of the reactor, the gas mixture has reached a temperature of at least 850°C. The process reactions take place from the bottom of the central tube onward and take less than one second to complete.

Figure B-3 is a process schematic of the entire system, including the reactor. Most of the system components are mounted on highway trailers for ease of mobility. The reactor trailer houses the reactor, the electric heating control system, the scrubber system, the recirculation gas blower, the recirculation gas heater, and the watery waste preheater vessel. A second trailer contains the main power distribution room, the dual-fuel steam boiler, the catalytic steam reformer, and an auxiliary burner for excess product gas. Cooling water for the scrubbing system is generated by skid-mounted evaporative coolers, and scrubber stripping operations are carried out on a small skid situated near the boiler. The product gas compression and storage system is also skid-mounted to allow flexibility in site layout. For processing soils and other solids, the thermal desorption mill (TDM) is housed on a separate trailer, and the sequencing batch vaporizer (SBV) is a skid-mounted unit. The process control system, gas analyzer systems, and command center are housed in a standard office trailer. Several feed systems are available for various types of wastes, depending on whether watery waste, oil waste, or solid waste is being processed. Watery waste is preheated in a preheater vessel using steam from the boiler. The contaminated steam from the preheater vessel is metered into the reactor at a rate determined by the process control system. Hot contaminated liquid exits the bottom of the preheater vessel at a controlled flow rate and enters the reactor through an atomizing nozzle. Oil waste can be metered directly from drums into atomizing nozzles using a diaphragm pump.

Solid wastes such as Soil or decanted sediment are decontaminated in the TDM with the desorbed contaminants being sent to the reactor through a separate port. The internal workings of the TDM are designed to vaporize ail water and organic contaminants in the waste soil/sediment while mechanically working the solids into a fine granular mixture for optimum desorption. The water vapor and organic contaminants are swept into the reactor by a sidestream of scrubbed recirculation gas.

Solids such as contaminated electrical equipment can be thoroughly desorbed using the SBVs. These chambers take advantage of the reheated recirculation gas stream to heat the equipment and carry contaminants into the reactor. The hydrogen atmosphere is nonreactive with most metals, and there are none of the problems with metal oxide formation associated with rotary kilns. The SBV can also be used for vaporization of drummed solid chemical wastes, such as HCB. Significant stockpiles of "hex wastes" exist and are still being generated as by-products of chlorinated solvent production. Advantages of vaporizing hex wastes directly from the drum

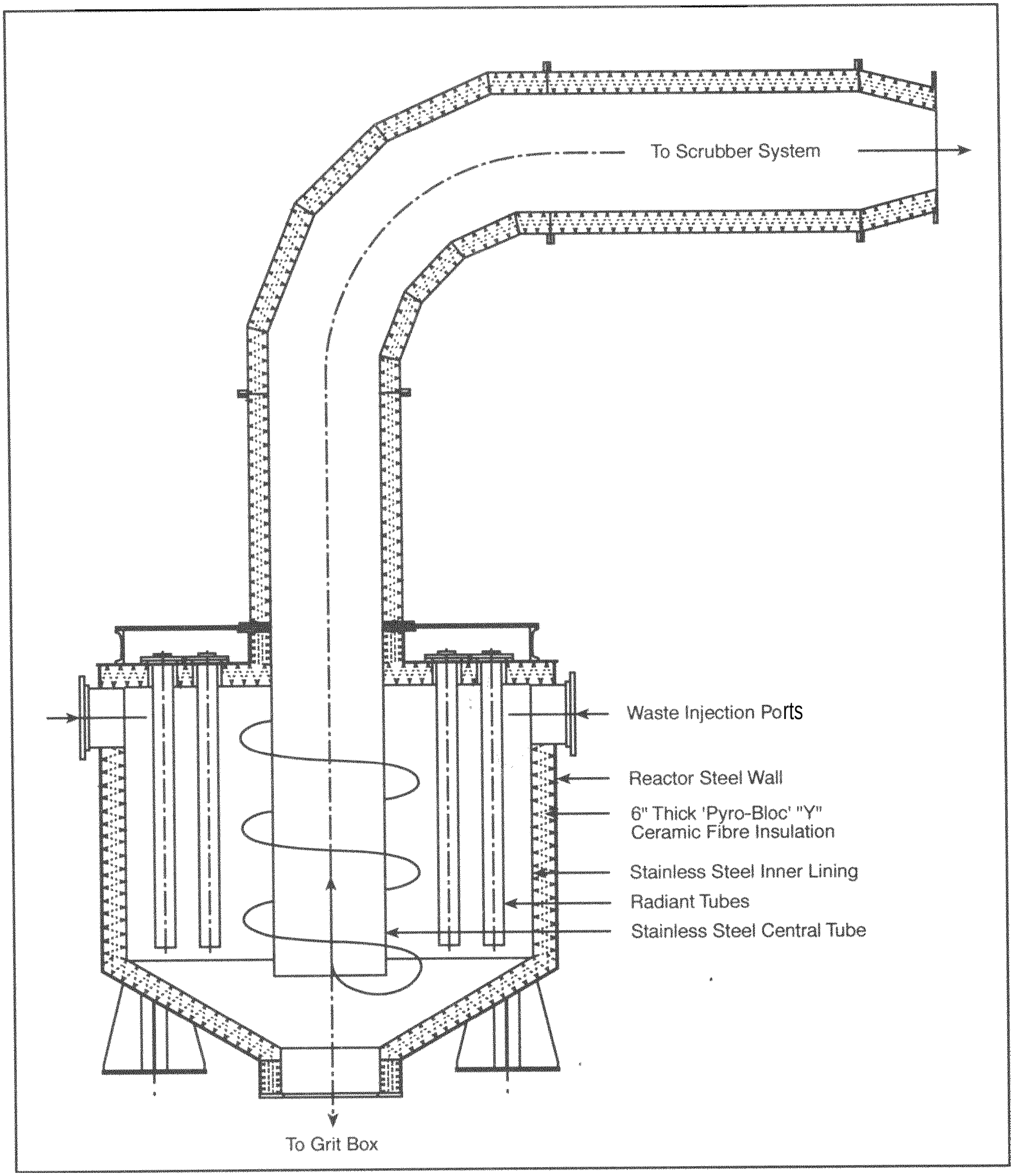


Figure B-2. **Commercial-scale process reactor.**

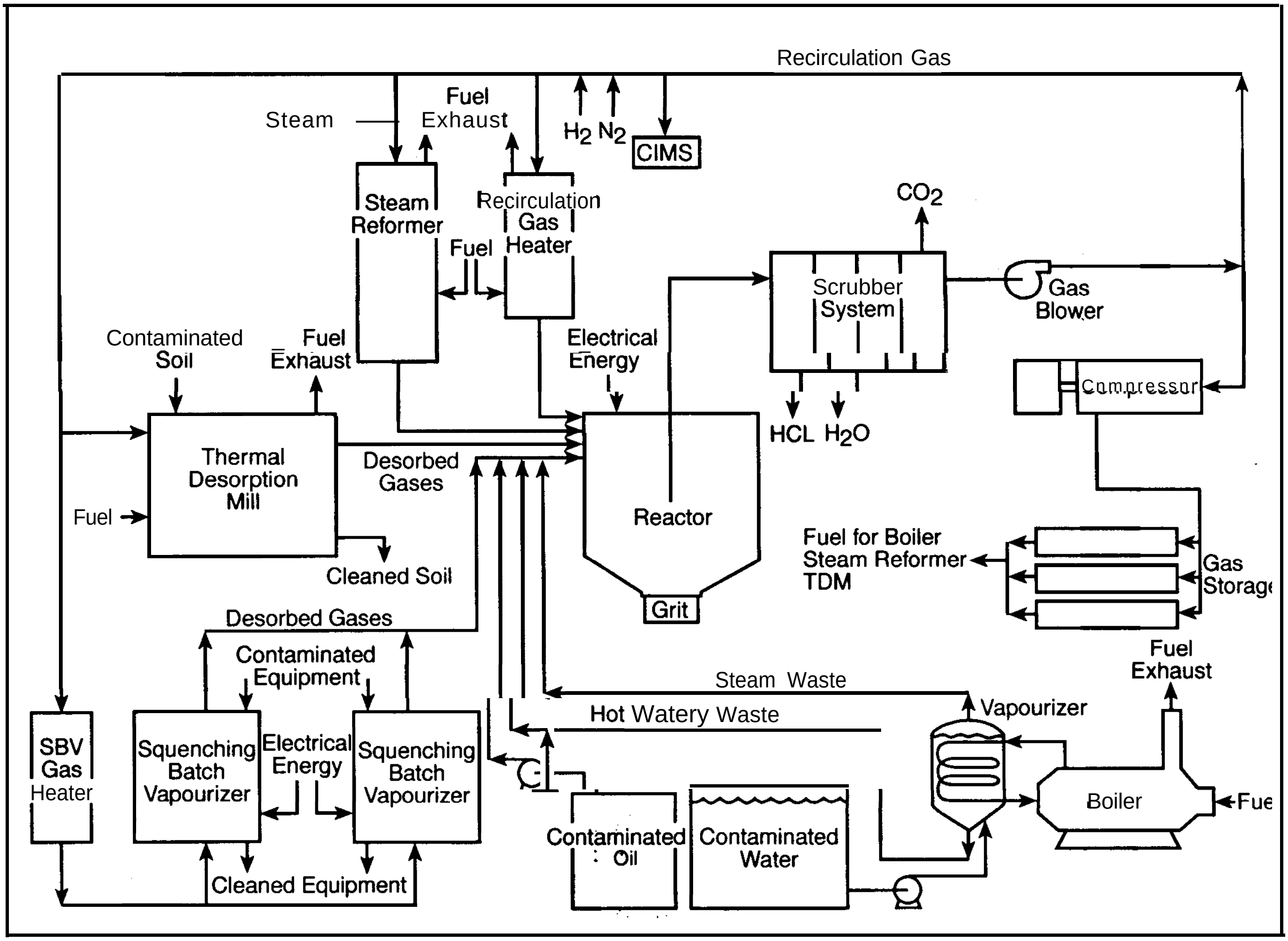


Figure B-3. Commercial-scale process unit schematic.

include decreases in worker exposures and fugitive emissions from drum transfer operations, cleaning of the drums in place, and segregation of inorganic contaminants into the existing drums. The SBV has been tested at lab-scale with hex waste samples and PCB-contaminated electrical equipment.

The product gas leaving the reactor is scrubbed to remove hydrogen chloride, water, heat, fine particulates, aromatic compounds, and carbon dioxide. The first stage of the scrubber can be operated to recover medium-strength hydrochloric acid, which avoids the cost of neutralization with caustic. The cost saving can be considerable if the waste stream is heavily chlorinated, the acid can usually be recycled, and generation of large volumes of salty wastewater is avoided. The second stage of scrubbing drops the temperature of the gas to remove water and completes the removal of hydrogen chloride by caustic packed tower scrubbing. Particulate matter, which may have entered the reactor as dissolved or suspended solids in the watery waste, is removed in both the first and second stages of the scrubber and is filtered out of the scrubber tanks continuously. Heat is removed using plate heat exchangers on the first two stages and cooling water from the evaporative cooling system.

The third stage of scrubbing removes low levels of benzene and naphthalene from the gas stream by neutral oil washing. The oil is stripped and regenerated with the benzene and naphthalene going to the inlet of the catalytic steam reformer. The fourth scrubbing stage is removal of carbon dioxide using monoethanolamine (MEA) absorption. The MEA is stripped and regenerated with the carbon dioxide going to the boiler stack.

The scrubber water from the stage-two scrubber leg returns to the covered section of the scrubber tank through a drop-tube that extends well below the water surface. This acts as a seal against air infiltration and as an emergency pressure relief mechanism. There will be no gas release if a short-term pressure surge forces gas out of the bottom of this tube since a check valve allows the gas to re-enter the system once the pressure returns to normal. The system normally operates within 10 inches water gauge (0.36 psi) of atmospheric pressure.

As waste is processed through the system, acid and water are produced as effluents. Filtered acid is pumped to a storage tank for further activated carbon treatment prior to recycling.

Excess water is also filtered and carbon-treated to remove any trace of organic contamination and is then stored for analysis prior to discharge. Carbon can be regenerated on-site in the SBV, and the minor amount of scrubber sludge produced can also be processed through the TDM or SBV.

The cooled and scrubbed product gas is a clean dry mixture of hydrogen, methane, carbon monoxide, and other light hydrocarbons. Some of the gas is reheated and recirculated back into the reactor to increase the methane concentration in the reactor when processing low-strength wastes. Recirculation gas is also directed to the TDM as sweep gas, to the SBV as sweep gas, to the catalytic steam reformer for hydrogen generation, or to the compressor for storage.

Throughout waste processing operations, the product gas is sampled for analysis by the CIMS and other gas analyzers. The CIMS is capable of accurately monitoring up to 10 organic compounds every few seconds at concentrations ranging from percent levels down to ppb levels. It is used as part of the EC0 LOGIC Process to monitor the concentrations of certain compounds indicative of the process destruction efficiency. The compounds selected for monitoring depend on the waste being processed. For example, during PCB processing, monochlorobenzene is typically monitored as an indicator of destruction efficiency. Low levels of this volatile compound indicate that destruction of the PCBs is proceeding to completion. The CIMS readings are monitored by the process control system, and the exceedance of alarm limits sends a message to the operator (low-level alarm) or automatically curtails waste input (high-level alarm). The CIMS also provides a continuous record of the quality of the product gas being compressed and stored.

Storage of the product gas under pressure permits the analysis of large batches of gas prior to using it as fuel and allows the operation of the system in a "stackless" mode. Should the product gas not meet the quality criteria established, there will have been no emissions to the environment, and the gas can simply be reprocessed. Potential applications for the stored product gas include heating the TDM, the catalytic steam reformer, and the steam boiler. If more gas is generated than can be used for fuel, an auxiliary burner located at the bottom of the common boiler/steam reformer stack is used.

Demonstration Testing

The pilot-scale process plant was tested for the first time at Hamilton Harbor, Ontario, in 1991. The waste processed during those tests was harbor sediment contaminated with coal-tar at concentrations of up to 300 g/kg (dry weight basis). The harbor sediment was injected directly into the reactor as a 5- 10% solids slurry, since, at that time, the TDM had not been developed. Also, the system had no catalytic steam reforming or gas compression and storage capabilities, and the product gas was sent directly to the dual-fuel boiler burner. DREs of 99.9999% were calculated (see Table B-l), based on the total organic input and the PAHs analyzed in the boiler stack emissions.' During one test, the liquid waste input was spiked with PCBs to create a waste with a PCB concentration of 500 mg/kg. The concentration of PCBs in the air emissions, liquid effluent, and processed solids were below the detection limits for each, respectively. Based on the detection limits for the stack sampling trains, a PCB DRE of at least 99.9999% was achieved.

A second round of tests of the pilot-scale unit was conducted in 1992 in Bay City, Michigan, as part of the EPA SITE program. The wastes processed included oily PCB-contaminated water, high-strength PCB oil, and PCB-contaminated soil. As part of the demonstration, EC0 LOGIC constructed and commissioned a prototype TDU, which was the forerunner of the current TDM, and demonstrated the capability to compress and store the product gas generated. The results for the test program, confirmed by EPA,2 are shown in Table B-2. The SITE Program Project Bulletins and TER have been published and will be followed by the AARs.

The waste oil was obtained from beneath the Bay City landfill and was analyzed by EPA to contain 25% PCBs and percent levels of other chlorinated solvents. The contaminated soil was obtained from installation of the sump wells used to collect the oil, and the contaminated water was groundwater from the landfill. The test matrix called for three water/oil tests, three oil tests, and three soil tests.

The water/oil tests were to be nominally 4000 mg/kg PCBs, based on injecting the water and oil in a 100:1 ratio through

Table B-1. Hamilton Harbor Performance Test Results

Run	Target Analytes	Conc. in Waste (mg/kg)	Decant Water Conc. (µg/kg)	Grit Conc. (mg/kg)	Sludge Conc. (mg/kg)	Stack Gas Conc. (µg/m³)	DRE (%)
P1	**PAHs**	21,000	483	1.67	32.8	0.27	**99.9999**
P2	**PAHs**	30,000	680	7.76	56.1	0.23	**99.9999**
P3	**PAHs**	30,000	423	0.37	4.3	0.14	**99.9999**
P3	**PCBs**	500	ND	ND	ND	ND	**99.9999**

DRE = (Total Input - Stack Emissions) / (Total Input)
ND = Non-Detect

Table B-2. U.S. EPA SITE Program Results

Water/Oil and High-Strength Oil Tests

Run	Waste Type	Contaminant	Concentration (mg/kg)	Target DRE/DE	Achieved
1	Water/Oil	PCBs	4,800	99.9999	Yes
	Tracer	Perchloroethene	4,670	99.99	Yes
2	Water/Oil	PCBs	2,450	99.9999	Yes
	Tracer	Perchloroethene	2,360	99.99	Yes
3	Water/Oil	PCBs	5,950	99.9999	Yes
	Tracer	Perchloroethene	6,100	99.99	Yes
4	Oil	PCBs	254,000	99.9999	Yes
	Tracer	Perchloroethene	33,000	99.99	Yes
5	Oil	PCBs	254,000	99.9999	Yes
	Tracer	Perchloroethene	26,000	99.99	Yes
6	Oil	PCBs	254,000	99.9999	Yes
	Tracer	Perchloroethene	34,000	99.99	Yes

Soil Tests

Run	Waste Type	Contaminant	Concentration (mg/kg)	Desorption Efficiency (%)
1	**Soil**	**PCBs**	**538**	**94**
	Tracer	**HCB**	**12,400**	**72**
	Tracer	**OCDD**	**0.744**	**40**
2	Soil	PCBs	718	99
	Tracer	HCB	24.800	99.99
	Tracer	OCDD	1.49	99.8

the atomizing nozzle. Perchloroethene was added as a tracer compound. The oil tests were designed to process the high-strength oil at higher throughputs while demonstrating the ability to compress and store the product gas generated. Steam was added through a separate port, but liquid water was not co-injected with the PCB oil. Again, perchloroethene was added as a tracer compound. After oil waste processing, the stored gas was directed to the boiler for about 24 hours, and stack testing by the EPA subcontractor was conducted. The target DRE for the PCBs was 99.9999%. and this was achieved for all six tests. The target DE for the perchloroethene was 99.99%, and this was also achieved for all six tests. The SITE program analytical results for the input concentrations of the water/oil mixture and the high-strength oil are shown in Table B-2.

Soils with various contamination levels were mixed to produce a relatively homogeneous quantity of soil with a nominal 1000 mg/kg PCB concentration. The soil test runs were conducted after construction and commissioning of the new TDU was completed. During the first TDU test, contaminated soil was processed with a desorption efficiency of 94%, resulting in a processed soil PCB concentration of 30 mg/kg. This result was encouraging for a first run, but the desorbed soil was still above the TSCA disposal criteria of 2 mg/kg. The waste soil residence time inside the TDU was increased for the second run, and a desorption removal efficiency of 99% was achieved according to SITE program results. The tracer compound used for the soil tests was HCB, which was spiked at significantly higher concentrations than the PCBs. The hexachlorobenzene was also contaminated with significant levels of octachlorodibenzo-p-dioxin (OCDD). The desorption efficiencies achieved for the HCB and OCDD for Test 2 were 99.99% and 99.8%, respectively. Due to TSCA permit restrictions, only two runs were performed for the third test condition. It should be noted that the performance of the TDU is independent of the destruction process. The reactor destruction efficiencies for the desorbed contaminants were high for both TDU runs.

An additional component of the test program was a 72-hour endurance test aimed at demonstrating the continuous operation capabilities of the EC0 LOGIC Process. The equipment operated perfectly and the 72-hour test was concluded successfully.

Current Status

The EC0 LOGIC Process has been demonstrated to be a high-efficiency alternative to incineration for the destruction of PCB wastes. High water-content wastes and high-strength oils can both be processed with destruction removal efficiencies of at least 99.9999%. The ability to compress and store the product gases generated during processing means that no uncontrolled air emissions occur.

The existing pilot-scale unit is presently available for further research and development work including new applications such as mixed wastes (low-level radioactive PCBs), chemical warfare agents, and explosives. Further research and development over the last I8 months has focused on optimizing the process for commercial operations and improving the design of the soil/sediment processing unit. The TDM design currently under construction has now achieved excellent results in lab-scale research and development supported by the National Research Council Industrial Research Assistance Program. Soils and sediments have been desorbed from ppm and percent levels down to low ppb levels, which are orders of magnitude below disposal criteria. Table B-3 shows the results of a number of lab-scale TDM runs processing a variety of waste types. The SE25 commercial-scale system now under construction has a design capacity of 100-300 tonnes/day of contaminated soil or sediment and 20 tonnes/day of PCB askarel fluid. The cost of processing these waste streams is estimated at $400 and $2,000 per tonne, respectively. The first SE25 system is being exported to Australia and will begin operations with a contract from Australian government agencies for 200 tonnes of obsolete pesticide destruction. Construction of a second SE25 system is also commencing to serve the North American market, and this unit should be commissioned for commercial use by the end of 1994. EC0 LOGIC has made proposals to several major North American corporations and a number of government agencies for the cleanup of contaminated sites.

Treatability studies using EC0 LOGIC's lab-scale destruction system are continuing. The lab-scale equipment includes a TDM for processing soil or sediment and an SBV suitable for processing samples of chemical wastes or contaminated electrical equipment. Clients find that treatability studies are a cost-effective method for determining the applicability and effectiveness of the EC0 LOGIC Process to their waste problems.

The EC0 LOGIC Process is a proven technology for the destruction of high-strength PCB oil wastes and is suitable for the destruction of askarel fluids used in electrical equipment and PCBs and other organic contaminants in soils and sediments. EC0 LOGIC offers a cost-effective alternative to incineration and can provide a complete on-site destruction service for the owners of **hazardous** organic wastes.

References

I. WTC Newsletter, published by the Wastewater Technology Centre, Environment Canada, No. 2, March 1992. Contact: Mr. Craig Wardlaw, Project Scientific Authority, 905-336-4691.

2. Technology Evaluation Report, SITE Program Demonstration, Risk Reduction Engineering Laboratory, U.S. EPA, Cincinnati, OH 45268, July 15, 1994. Contact: Mr. Gordon Evans, SITE Project Manager, 513-569-7684.

Table B-3. Summary of Test Results from the Lab-Scale Thermal Desorption Mill

Waste Type	Waste PCB Concentration (ppm)	Grit PCB Concentration (ppm)
Soil (tarry, oily)	39	0.011
Soil (dry, sandy, PCB-spiked)	440	0.0039
Soil (dry, sandy, PCB-spiked)	520	0.0016
Sediment (muddy, fine, PCB-spiked)	710	0.026
Sediment (muddy, fine, PCB-spiked)	790	0.0097
Sediment (muddy, fine, PCB-spiked)	750	0.065
Sediment (muddy, fine)	7.3	0.0029
Sediment (muddy, fine)	8.3	0.0066
Sediment (muddy, fine)	8.3	0.0013
Sediment (muddy, fine)	420	0.0017
Sediment (muddy, fine)	420	0.012
Sediment (muddy, fine)	2000	0.044
Sediment (muddy, fine)	1200	ND (0.011)
Sediment (muddy, fine)	8.3	ND (0.005)